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HAMILTON HARBOUR
TECHNICAL SUMMARY
AND
GENERAL MANAGEMENT
OPTIONS

August, 1935

Ontario
Ministry of the Environment

The Honourable
Jim Bradley
Minister

Dr. Allan E. Dyer
Deputy Minister

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OPTIONS

Great Lakes Section
Water Resources Branch

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EXECUTIVE SUMMARY

Investigations carried out in Hamilton Harbour have concentrated on monitoring of water and sediment quality, the causes of oxygen depletion in the bottom waters during the summer season, the relationships between phytoplankton biomass, bacteria, nutrients and physical factors, and on sources and fate of trace contaminants in the harbour. Investigations have been carried out by the Water Resources Branch of the Ontario Ministry of the Environment and through a contract with McMaster University.

The aim of these investigations, particularly with respect to oxygen depletion and nutrient problems, was to formulate management options to control and improve the water quality in the harbour. To reach this objective, investigations have concentrated on the control of the inputs of nutrients and oxygen-demanding substances to the harbour, the processes that control their fate in the harbour, and their export to the lake. An understanding of some of the physical, chemical and biological controlling processes has led to the development of an oxygen model which enables predictions of the most effective management schemes.

The dissolved oxygen and phytoplankton-nutrient problems are interrelated. Phytoplankton species observed in the harbour are typical of a highly enriched body of water. Phytoplankton, which are responsible for the production of large amounts of organic carbon and nitrogen in the harbour, are not growth limited by either phosphorus or nitrogen. The algal biomass is, at present, limited by the vertical instability of the water column and the shallow light penetration.

The major microbial processes governing the high water column oxygen demand, which causes the low dissolved oxygen levels in the harbour, are nitrification, sulphur oxidation and organic carbon decomposition. These processes vary seasonally as the dominant factor governing oxygen demand. Therefore, abatement measures aimed at alleviating the dissolved oxygen problem in the harbour must address a variety of chemical inputs, rather than focusing on a single substance.

Bacterial oxidation of ammonia and both the externally and internally generated organic matter results in severe dissolved oxygen depletion in the bottom waters. In order to limit bacterial activity in the harbour and maintain dissolved oxygen levels at or above Ministry objectives, the oxygen model predicts that both ammonia and the external and internal loads of organic material must be dramatically reduced in the water column. In order to reduce the internal load, phytoplankton densities must be restricted by a phosphorus limitation. This can only be achieved by radically reducing the phosphorus input from the major sources, in particular, the Hamilton STP (Sewage Treatment Plant), to about 0.1 mg/L.

With the removal of the oxygen demand in the water column, the oxygen levels will be controlled by the existing sediment oxygen demand. The rate at which this demand will be reduced, once inputs of organic and chemical oxygen demanding substances have been removed, is not known.

Trace metal sources are fairly well established with the steel industries inputting the greatest amount. Very little is known about the inputs of trace organics; however, sanitary and storm sewers may be the major sources of pesticides and chlorinated hydrocarbons, while steel mill processes may introduce polyaromatic hydrocarbons. Very little information exists on the fate of trace metals and organics or on their effects on the biota in the harbour. As over 90% of the loading of suspended solids into the harbour is retained in the harbour, that fraction of the trace organics and metals associated with the particulates is also retained. However, 80 to 90% of the mass of organics in the water column is in the aqueous phase. Since the hydraulic residence time is about 90 days (or 0.25 yr on average) the amount exported to the lake is about four times the mass present in the water column at any time. In addition, since 20 to 80% of the trace metals are in the particulate form in the water column, the export of trace metals to Lake Ontario is, approximately equal to (within a factor of two) the amount settling out on the sediments. However, the harbour is not a significant source, of trace metals or organics to Lake Ontario when compared to airborne or Niagara River inputs.

Biological availability of trace contaminants is greatly influenced by ambient chemical conditions and the presence of complexing organic and inorganic particulate matter. The actual effects of a heterogeneous mixture of sediment contaminants on the ecosystem is presently unknown. This problem is both a subject of concern and the object of intensive investigation throughout the Great Lakes Basin.

Surveys conducted by Fisheries and Oceans Canada have found a high incidence of neoplasms (tumours) on a variety of fish caught in the harbour; for example, about 40% of white suckers caught in the harbour have lip papilloma, a condition which is believed to occur as a result of deteriorating water quality and contaminated sediments. These surveys also indicate two other elevated incidences of the disorder throughout the western nearshore areas of Lake Ontario.

The water and sediment qualities in the harbour are consistent with those expected in a water body of restricted flushing and large inputs of industrial and municipal wastes. The average annual concentrations of ammonia and zinc throughout the harbour exceed the Provincial Water Quality Objectives. Iron and phenols also exceed Objectives occasionally. Water quality is generally worst in the southeastern portion of the harbour, adjacent to the discharge sites. Harbour sediments are severely contaminated in some areas. Many substances including metals and PCB's (Polychlorinated Biphenyls) exceed the Ministry's guidelines for open water disposal of dredged spoils.

In view of the stringent measures needed to improve the dissolved oxygen levels and to reduce phytoplankton biomass, an indepth cost/benefit analysis must be carried out before undertaking any further reduction in effluent quantity or improvements in effluent quality. Because of the short flushing time of the harbour (approximately 3 months), improvements in water quality resulting from reduced loadings should be apparent within a year. However, the sediments could prove to be a significant source of contamination to the water column, thus masking the anticipated improvements to water quality and lengthening the time for recovery.

The following areas are in need of further study:

- o the characterization and quantification of inputs of trace contaminants in the effluents, especially of trace organics, their fate, and effects on biota;

- o the rate at which the oxygen demand of sediments will decrease as inputs of oxygen demanding substances are reduced, and whether management options such as dredging are cost-effective in reducing the sediment oxygen demand;

- o the effects of harbour outflows on the nearshore region of Lake Ontario with special attention to the Hamilton and Burlington water supplies.

- o the extent of the release of contaminants from sediments as inputs are decreased.

In addition, if further remedial measures are instituted, improvements in water and sediment quality and concomitant changes in biomass should be monitored.

Water quality in Hamilton Harbour is dictated by both land use and urban discharges throughout the basin. Available management options include those allowing for further water quality deterioration, those providing for the maintenance of existing quality, and those which will result in improved water quality. Factors such as the present significance and future potential of the resource, and the desired uses of the harbour should be used to select the most suitable management approach.

GENERAL CONCLUSIONS

Additional Summary and Conclusions are located at the end of each Section.

Sect. 1 Temperature Structure, Currents and Lake Harbour Exchange

The harbour is physically very dynamic. A strong, permanent thermocline does not develop in the harbour in the summer; therefore, there is considerable exchange between the top and bottom layers. The large, lake-harbour exchange flows through the canal that, combined with wind- generated motions, produce vertical mixing. However, this is not sufficient to make the water column in the harbour uniform, since horizontal and vertical gradients in temperature and water quality remain. Because of this variability, it is difficult to detect changes in the water quality in the harbour without an intensive program of measurements, and changes due to remedial measures would have to be large to be measured with certainty.

Exchange through the Burlington Ship Canal dominates the hydraulics of the harbour and has a major effect on water quality. The average residence time of the harbour is around 90 days; without exchange flows, the residence time would be approximately 430 days. The shorter residence time dilutes the municipal and industrial effluents entering the harbour more effectively. This also implies a greater effect of the diluted effluents on the western end of Lake Ontario. A shorter retention time in the winter and hypolimnetic lake-harbour exchange in the summer tend to enhance harbour water quality through dilution and displacement.

Sect. 2 Loadings to the Harbour and to Lake Ontario

Although the best available information has been used in calculating the loadings, the model budgets given should be accepted with reservation. The calculated loadings for BOD (Biochemical Oxygen Demand), suspended solids and nutrients are more reliable over the several years since the information was collected in a consistent manner and are supported by the changes in the harbour concentration.

The annual loading data show that the Hamilton sewage treatment plant is the major source of phosphorus, ammonia and BOD to the harbour. While ammonia loadings decreased from 1977 to 1979, phosphorus (P) loadings increased over this same period, and contributed to increased harbour P levels. From 1979 to 1983, however, loadings have decreased significantly.

The steel industries are the major source of several heavy metals, phenols, cyanide and suspended solids but have shown a decrease from 1979 to 1983. Industrial and municipal sources currently contribute similar quantities of COD (Chemical Oxygen Demand). Storm sewers may be a source of PCB's and other organo-chlorines, while the steel mills and the Hamilton STP are the major sources of polynuclear aromatic hydrocarbons (PAH's). Additional work is needed to define these loadings more accurately.

Compared to loadings from the Niagara River and the atmosphere, the harbour is a minor source of trace organics and trace metals to western Lake Ontario.

Sect. 3 Water and Sediment Quality

Concentrations of nutrients and other water quality variables show a rise from 1975 to 1979, followed by a drop that is ongoing due to the changes in loadings to the harbour. The reduction in concentrations of water quality parameters is not as rapid as the change in loadings.

Average levels of ammonia, zinc and turbidity exceed the Provincial Water Quality Objectives. Iron and phenols also exceed the Objectives on an occasional basis. In addition, extremely low dissolved oxygen levels have been observed in the hypolimnion during the stratified period. Temporal trends for trace organics cannot be seen due to lack of a complete and reliable data set.

The sediments with the highest contamination levels are found in the deep water depositional area and near the major outfalls. Less contaminated sediments are found in the silty areas along the north shore and near the Burlington ship canal. The average sediment

concentrations of almost all parameters, including trace metals, exceed Ministry of the Environment Guidelines for dredged spoils disposal in open water, and are higher than average levels found in Lake Ontario. Decreasing sediment concentrations of iron, zinc, manganese and copper have been measured between 1980 and 1982.

There is very little information on the fate of trace metals and trace organics in the harbour. Over 80% of the loadings of suspended solids into the harbour is retained in the harbour. Therefore, the trace contaminants associated with these particulates will also be retained and settle out to the bottom. However, most of the total mass of organics is in the dissolved phase because of the relatively low concentration of particulates and more is exported from the harbour than settles to the bottom.

Sect. 4 Phytoplankton

Primary production is responsible for the fixation of both organic carbon and nitrogen in amounts which are between 0.2 and 1.6 times the daily external loads (for 1979). Since bacterial actions on organic carbon and nitrogen have been identified as major causes of the severe dissolved oxygen problem in the harbour, primary production represents a significant reservoir of oxygen demanding material. Any attempt to rectify the dissolved oxygen problem in the harbour must include the reduction of primary production.

Phytoplankton biomass in Hamilton Harbour is not limited by nitrogen or phosphorus at present. The depth of the water column through which photosynthesis occurs, at rates sufficient for algal growth (euphotic zone), is very shallow and is governed by the high levels of suspended solids and dissolved organics present in the harbour. A reduction in the load of these materials, in the absence of significant reductions to the phosphorus load, could result in an increase in the average summer phytoplankton biomass level. Therefore, all abatement measures should be carefully co-ordinated to avoid a potential impairment of certain aspects of water quality.

Sect. 5 Bacterial Populations in Hamilton Harbour

Fecal coliform levels have declined steadily since 1975 to a point where the swimming and bathing criterion (100 counts/100 mL) is seldom exceeded.

Population densities of nutrient cycle bacteria are extremely high in the harbour. Their combined activities (nitrification, sulphur oxidation and organic carbon decomposition) are responsible for the high oxygen demand present in the water column.

Although all three processes are active throughout most of the year, they exchange positions as the dominant oxygen demanding process on a seasonal basis. Therefore, abatement measures aimed at alleviating the dissolved oxygen problem in the harbour must address a variety of chemical inputs, rather then focusing on any single substance.

Sect. 6 The Dissolved Oxygen Regime in the Harbour

Between June and September, the oxygen content in the hypolimnion approaches zero and the epilimnion is below saturation even as late as mid-December. The cause of the oxygen depletion is the bacterial oxidation, in the water column and the sediments, of reduced carbon, nitrogen and sulphur which are present in effluents. Additional oxygen demand results from phytoplankton growth and decay. Reaeration, photosynthesis and inflows from the lake add oxygen and keep the hypolimnion from becoming continuously anoxic.

An oxygen model has been developed, and used to predict effects of remedial programs; chiefly of reducing inputs from industry and sewage treatment plants. Abatement scenarios such as the diversion of effluents to Lake Ontario are predicted to approximately double the hypolimnetic oxygen concentration, but will leave it well below the Objective. The reduction of nitrogen loads will have a greater effect on reducing oxygen depletion than the reduction of organic carbon loads, but only the removal of all water column oxygen demand will bring hypolimnetic dissolved oxygen close to compliance with the Provincial Water Quality Objective. In order to improve oxygen conditions, the internal load - phytoplankton growth - must be greatly reduced.

1.0 TEMPERATURE STRUCTURE, CURRENTS AND LAKE - HARBOUR EXCHANGE

1.1 General Description of Harbour and its Watershed

Hamilton Harbour (Fig.1.1) is located at the western tip of Lake Ontario. It is approximately triangular in shape with a base (east-west) of about 8 km and a height (north-south) of about 5 km. It is divided from the lake by a sandbar pierced by the Burlington Ship Canal (840 m long, 85 m wide and dredged to 9.2 m; International Great Lakes datum). The Desjardins Canal at the western tip of the harbour connects it to Cootes Paradise. The two main rivers flowing into the harbour are Grindstone Creek (western tip) and Red Hill Creek (eastern tip). Other minor rivers are situated along the northern shore. Locations of the numerous industrial and municipal intakes and outfalls, including storm sewers, are also shown on the same figure. The volume of the harbour is about $2.8 \times 10^8 m^3$; the area, $2.2 \times 10^7 m^2$; and the mean depth, 13 m (MOE 1974). A basin with depths of 20 to 24 m exists just east of the center of the harbour. A smaller basin is found to the south of the Burlington Ship Canal entrance with depths of 15 to 20 m. (Fig.1.2). Considerable filling, leading to a decrease of the harbour volume and area, has occurred in the harbour since the early part of this century. For example, in 1926, the volume and the area were, respectively, $2.95 \times 10^8 m^3$ and $2.8 \times 10^7 m^2$.

The total drainage area of the watershed is 49.4×10^7 m^2 or 22 times the harbour surface area. Cootes Paradise, Grindstone Creek and Red Hill Creek are the major sub-watersheds of the harbour. Hamilton stormwater overflows drain the combined stormwater-sanitary sewage from the area of Hamilton below the mountain and flow directly into the harbour. While the drainage area of these systems is small, their impact on the harbour can be large due to their substantial pollutant load. The major runoff period is February to April, and the total annual runoff is about 1.1×10^8 m^3. The annual rainfall averages from 65 to 108 cm.

The urbanization and industrialization of the harbour's watershed have also influenced the water quality in the harbour. At present, a large industrial infrastructure, including Canada's two largest steel mills, discharge to the harbour. The sanitary sewage of approximately 474,000* people is treated at the Hamilton, Burlington, Dundas and Waterdown sewage treatment plants and then discharged to the harbour.

1.2 Thermal Structure

Between mid-October and May, the harbour is isothermal from top to bottom. The ice cover (the harbour is seldom completely frozen over) disappears around mid-March. The harbour warms up until mid-July when average temperatures between 22 and 24^{o}C in the epilimnion are reached. The harbour then starts to cool, reaching around 10 to 12^{o}C at the beginning of November. The hypolimnion reaches maximum temperature in September-October, when the harbour begins to turn over. Figures 1.3a and 1.3b show the observed temperatures for 1978.

In mid-summer, an unstable thermocline is typically found. Rarely does the difference from top to bottom in the water column exceed 12^{o}C, however, lake oscillations induce perturbations of several meters in the thermocline depth within time spans of minutes. Weather conditions influence the surface temperature over short-term intervals, producing brief periods of surface warming followed by partial overturn, a pattern observed several times each year.

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* Estimates based on: Hamilton-320,000; Dundas-20,000; Ancaster-15,000; Burlington-sanitary sewerage from 90,000; storm water discharges from 30,000; Stoney Creek-sanitary sewerage from 25,000, estimated from 6,235 water meters at 4 people/meter).

Since a stable thermocline is not a permanent feature, considerable mixing takes place between the top and bottom layers of the harbour. The diffusion coefficients in the thermocline region of the harbour calculated from the vertical oxygen gradients are at least ten times higher than in the thermocline of Lake Ontario (Polak 1981). The oxygen model developed for the harbour (see Sec. 5) suggests, however, that the diffusion coefficient should be lower than these calculations indicate.

The Burlington Ship Canal is stratified from May to August and weakly stratified in September and October. The temperatures in the bottom layer when the flow is into the harbour are the same as for the thermocline region of Lake Ontario. The inflowing water, being denser, will therefore flow along the bottom of the harbour. The temperatures in the Desjardins Canal were always higher than in the Burlington Canal since the shallow Cootes Paradise is warmer than the harbour.

1.3 Currents in the Harbour

Currents have been measured on several occasions (Fig.1.4) between May and November (1972-1981) in the harbour and for twelve months in the Burlington Canal in 1979-1980.

The currents in a water body are influenced by wind, density differences, bottom friction, the earth's rotation and the size and geometry of the water body. The surface currents are predominantly influenced by wind force and directions, while the currents in deeper water are affected by the other factors as well. The speed of the currents generally decreases with depth in a non-stratified regime (winter). However, during a stratified regime (summer), the current speed decreases from the water surface to the thermocline level and then starts to increase again while reversing the direction to reach a peak value in the mid-hypolimnion and decreasing again to the lake bottom. The currents are generally variable in speed and direction with time.

At mooring 18 (Fig. 1.4), the measured currents rotate both clockwise and counter clockwise, changing in direction every one or two days (Fig. 1.5). At 1103 and 1104, the currents were generally variable in both direction and speed. Under an ice-cover, the surface currents were slower than at depth because of the wind stress and increased drag of the ice (Kohli 1978).

Spectral analysis of the currents shows many periodicities and a strong influence of Lake Ontario's oscillations on harbour movements. High frequency periods of 0.1 - 0.2 hours have been measured. These high frequency motions are also reflected in the very high degree of small-scale variability (in the order of 5-25m) present in the chemical and biological variables (Harris, et al. 1980).

Red Hill Creek, the Hamilton sewage treatment plant and several industrial outfalls empty into the Windermere Channel and Basin (See Fig. 1.4 for extent). The volume of the Channel is about 6.2 x $10^6 m^3$ or 2.3% of the harbour volume. The flow from the outfalls is about 3 x 10^5 m^3/d with approximately 80% arising from the sewage treatment plant. Therefore, the residence time (the time it takes to completely replace the water in the channel by the outflows from Redhill Creek and the Hamilton STP) is about 21 days, which is 1/5 to 1/3 of the harbour's residence time. Because of the shallowness of the Basin (mean depth less than 1 m), variations in water level cause the residence time of the Basin to fluctuate 1 to 2 days. In other words, pollutants introduced to the Channel take about 3 weeks to be flushed out. Circulation in the Channel, as measured by drogues, is complex and depends strongly on wind direction and bottom configuration. During the stratified periods, surface currents are generally in the direction of the wind and about twice as fast as bottom currents. Flows into the channel or across it were observed at the bottom. Generally the flow from the channel is directed towards the Burlington Canal, but some of the flow is mixed into the main body of the harbour before flowing through the canal.

1.4 Lake-Harbour Exchange

The flows through the Burlington Ship Canal are very complex and seasonably variable. During the unstratified period (October to May), flow is in the same direction at all depths, but oscillates back and forth. In the stratified period, there is a layer of warm harbour water flowing out on the top and a layer of colder lake water flowing in at the bottom for most of the period. Both of these flows are also oscillatory (Fig.1.6) with periods ranging from about twenty minutes to half a day. Most of the observed periodicities correspond approximately to the theoretical oscillation and inertial periods of Lake Ontario and of Hamilton Harbour and to semi-diurnal periodicities. These are independent of local wind stresses. On rare occasions, the lake water flows in at the surface while harbour water flows out at the bottom. Flows in the same direction in both layers or three or more layer flows have also been observed on occasion. As a result, water quality and temperature also show strong periodicities in the canal (Fig.1.7). In the top layer, the resultant currents ranged from 0.6 to 13 cm/s while a maximum speed recorded was 130 cm/s. (Palmer and Poulton 1976; Kohli 1979; Haffner, Poulton and Kohli 1982.)

Intrusive tongues of lake water with high oxygen content have been detected during the summer months in the bottom layer of the harbour. The tongues spread from the canal up to two-thirds of the way to the Stelco property and up to 1.5 km laterally. The mathematical model developed for calculating flows in the Canal (Kohli 1984) predicts an average calculated excursion distance of lake water into the harbour of 600 m with a range of values from 80 to 1162 m. The oxygenated water spreads primarily west and north rather than into the basin to the south of the canal. Excursion distances are generally higher in the period from September to January in association with increased current speeds.

The average daily flows calculated from the model and based on actual current measurements in the canal are given in Table 1.1 for each month for the period May, 1979 to April, 1980. The net flow to the lake is approximately equal to municipal sewage treatment plant flows, storm water flows, flows from Cootes Paradise and from tributaries.

If these flows and the net outflow are not in balance, the water level in the harbour would change. The measured and calculated fluctuations of water level are in balance over a period of a year, although they differ from month to month.

Of the total input to the harbour - excluding the exchange flows - about 51% is from the sewage treatment plants, 32% from tributaries and storm water, and about 15% from Cootes Paradise. Although the industries withdraw about 2.0 to 2.3 x 10^6 m^3/d from the harbour, this water is used chiefly for direct contact cooling and, except for a small fraction (0.4%), is returned to the harbour. The Burlington and Hamilton municipal drinking water treatment plants both take their raw water from Lake Ontario.

Other estimates of flow are calculated from water level differences at the two ends of the canal, estimated from budgets of conservative dissolved substances into the harbour, or based on current measurements over only part of the year (Kohli 1984). The agreement between the mean flows is better than between the maximum and minimum flows of individual studies. There are no direct measurements of year-to-year variations in exchange flow but calculations based on total nitrogen budgets for the years 1975-1979 suggest that the mean yearly flow does not change more than a few percent (Klapwijk and Snodgrass 1985).

Both the net flow to the lake and the in- and outflows (Table 1.1) show considerable between month variation, with the largest gross and net flows in the winter and the lowest in the period of July to October. Consequently, the residence time of the harbour (harbour volume/flow to the lake) is the shortest in the winter and spring and longest in the summer. On average, 3.3 x 10^6 m^3/d or 1.2% of the harbour volume flows towards the lake and 2.7 x 10^6 (1.0%) returns via the canal, leaving a net outflow about 0.2%.

1.5 Summary and Conclusions

1. The harbour is physically very dynamic. A strong, permanent thermocline does not develop in the harbour between the top and bottom layers during the summer; therefore, there is considerable vertical exchange of water. The large lake- harbour exchange flows through the Burlington Canal, combined with wind- induced motion, produces large changes in the vertical thermal structure and a very high degree of small scale variability or patchiness in the thermal, chemical and biological properties of the harbour. This mixing, however, is not sufficient to make the water column in the harbour vertically uniform, as evidenced by the observed gradients in temperature and water quality. Chemical and biological processes (see sections 4 and 5) accentuate the gradients in water quality. Subtle changes in water quality are difficult to detect because of these gradients and as such intensive monitoring would be necessary to observe improvements due to remedial measures.

2. The exchange through the Burlington Canal dominates the hydraulics of the harbour and has a major effect on the water quality. The average residence time of the harbour is 90 days. Without the exchange flows, the residence time would be approximately 430 days. The shorter the residence time, the more efficient the dilution of the effluents - industrial and municipal - added to the harbour, and the quicker the removal of the diluted effluents from the harbour to Lake Ontario. Since the retention time in winter is shorter than in the summer, the dilution is more efficient in winter than in summer.

   The inflow of relatively cleaner and colder lake water with an oxygen content close to saturation into the hypolimnion during the summer increases the oxygen content and the water column stability in the harbour.

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TABLE 1.1: HAMILTON HARBOUR WATER BUDGET 1979-80

FLOW X 1000 m^3/d

	To Lake	To Harbour	Net To Lake	Total Input	Change in Harbour Volume	Equivalent Water Volume Fluctuation*	Residence** Time (days)
	L	H	N	Q	(Q-N)	W	R
May 79	2112	1696	416	612	+196	+ 98	133
Jun 79	3234	2646	588	521	- 67	- 29	87
Jul 79	2464	2016	448	397	- 51	- 83	114
Aug 79	2844++	2327++	517	458	- 59	- 71	98
Sep 79	2690++	2201++	489	433	- 56	- 37	104
Oct 79	2651++	2169++	482	427	- 55	- 69	106
Nov 79	3784	3096	688	609	- 79	-110	74
Dec 79	4648	3803	845	748	- 97	- 8	62
Jan 80	4769	4268	501	724	+223	+ 16	59
Feb 80	2766	2323	443	479	+ 36	+ 20	101
Mar 80	3794	2649	1145	1047	- 98	- 10	74
Apr 80	4032	2844	1188	1296	+108	+287	69
Total	39738	32038	7750	7751	+ 1	- 3	1081
Mean	3316	2670	646	646	0	0	90
	(38.4)***	(30.9)	(7.5)	(7.5)			

* Equivalent harbour volume fluctuations due to measured water level fluctuations in the harbour over the same time period; + indicates that water level in the harbour increases, - that it decreases

** Residence Time = Harbour Volume/Flow Rate to Lake (L)

*** Flows in m^3/s

++ Estimated flows

Harbour Volume = 2.8×10^8 m^3
Harbour Area = 21.5×10^6 m^2
Mean Harbour Depth = 13 m

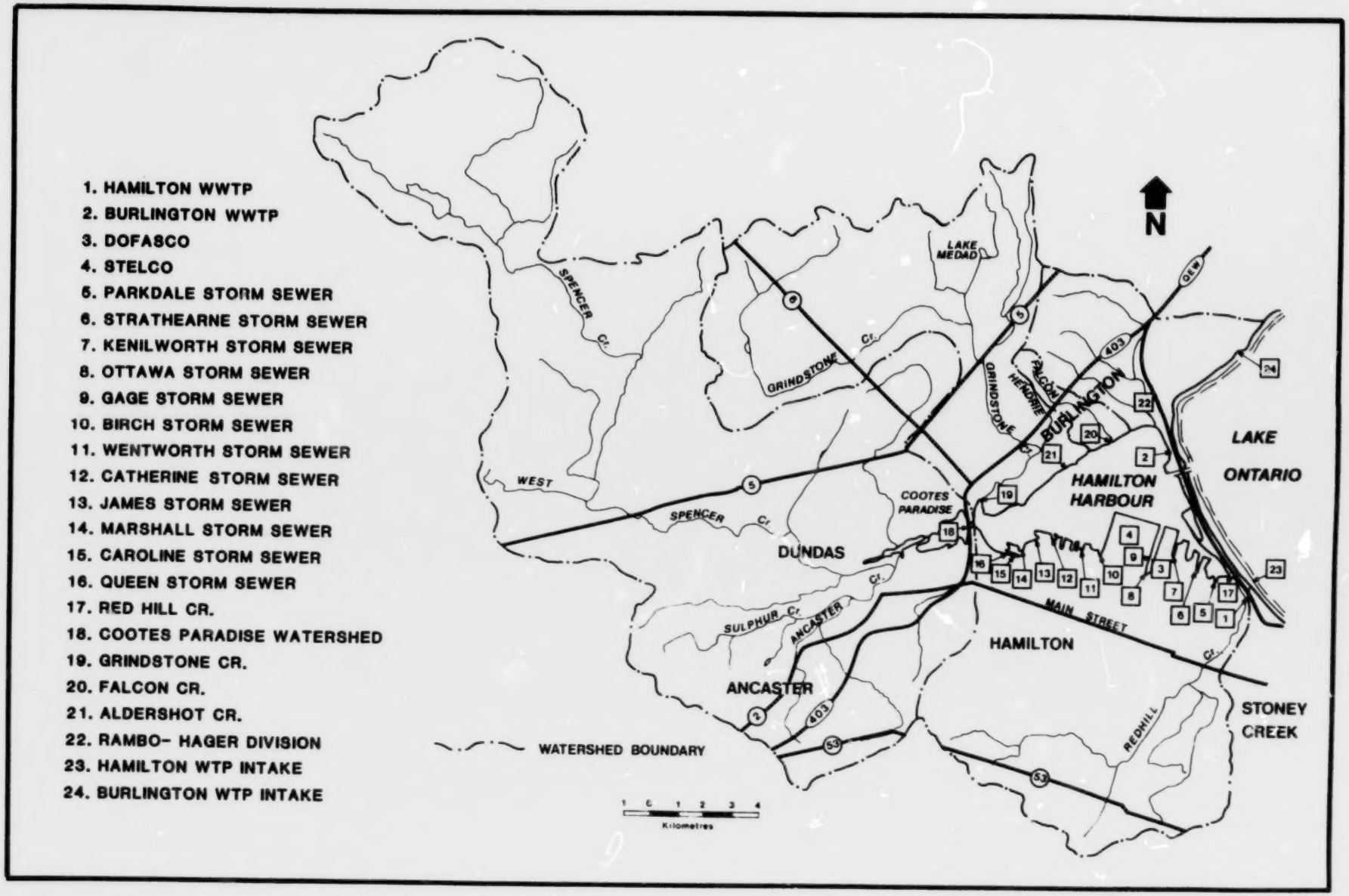

FIGURE 1.1 : HAMILTON HARBOUR WATERSHED

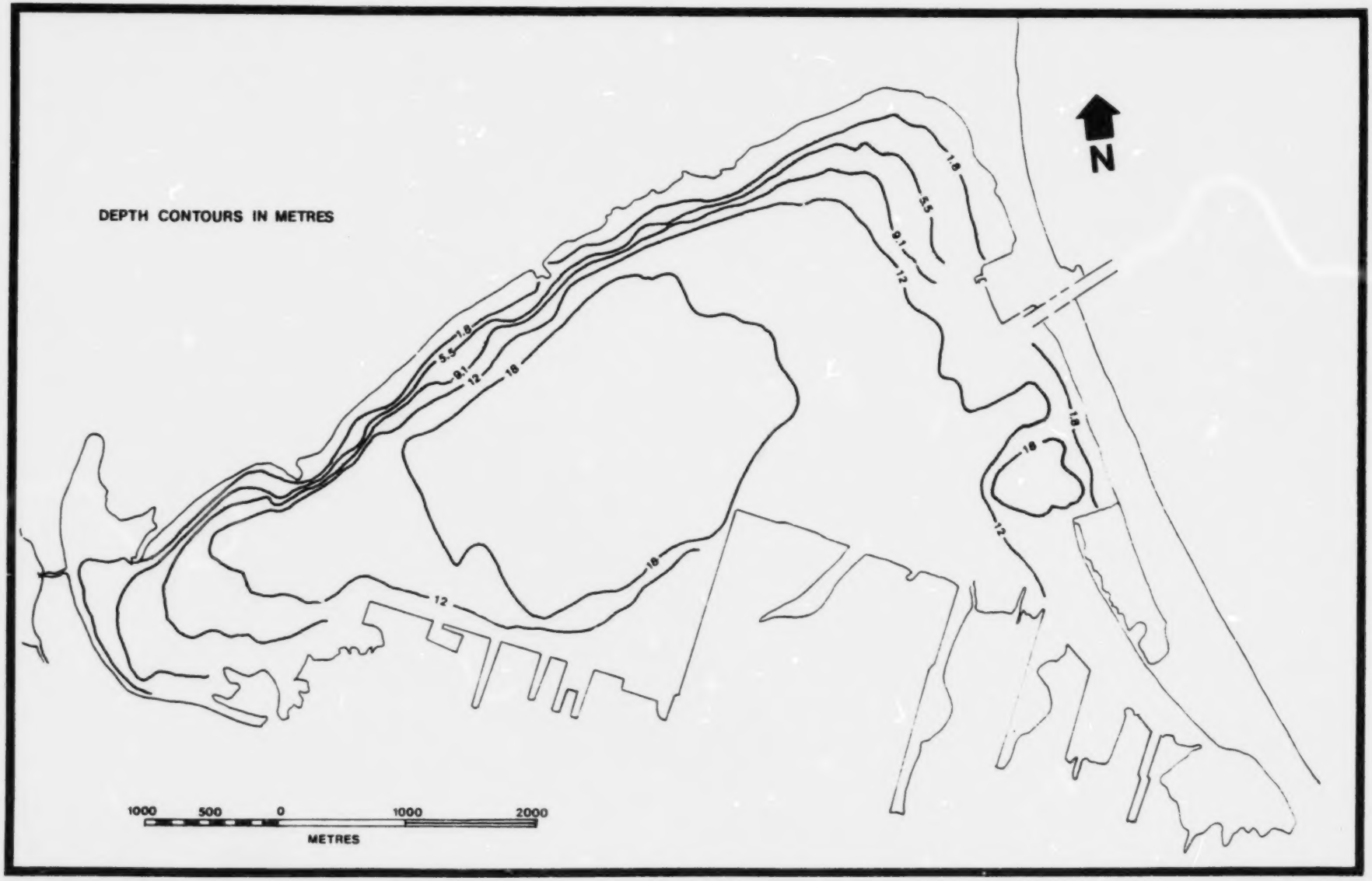

FIGURE 1.2 : HAMILTON HARBOUR BATHYMETRY

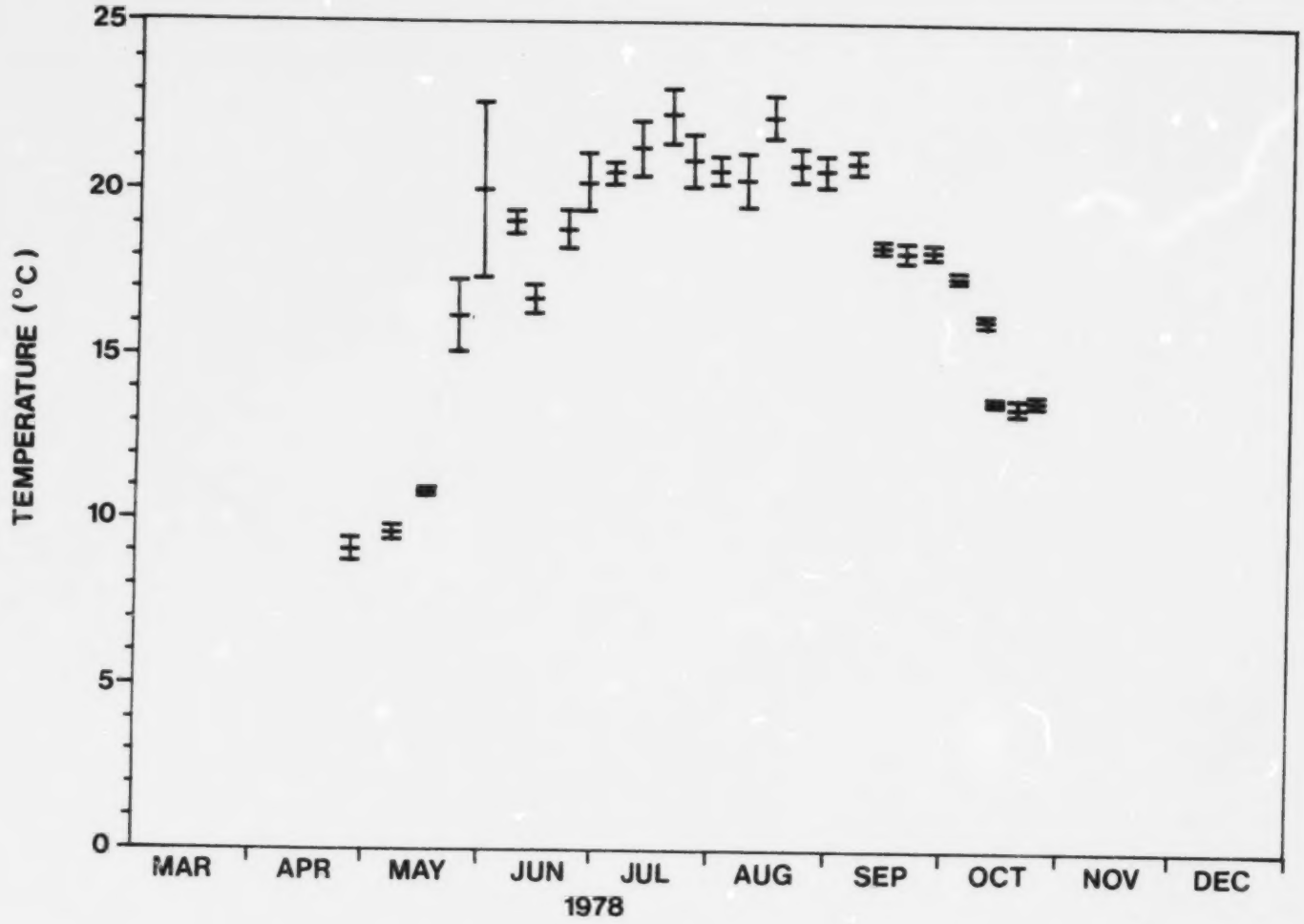

FIGURE 1.3a : OBSERVED TEMPERATURES FOR THE TOP LAYER OF HAMILTON HARBOUR

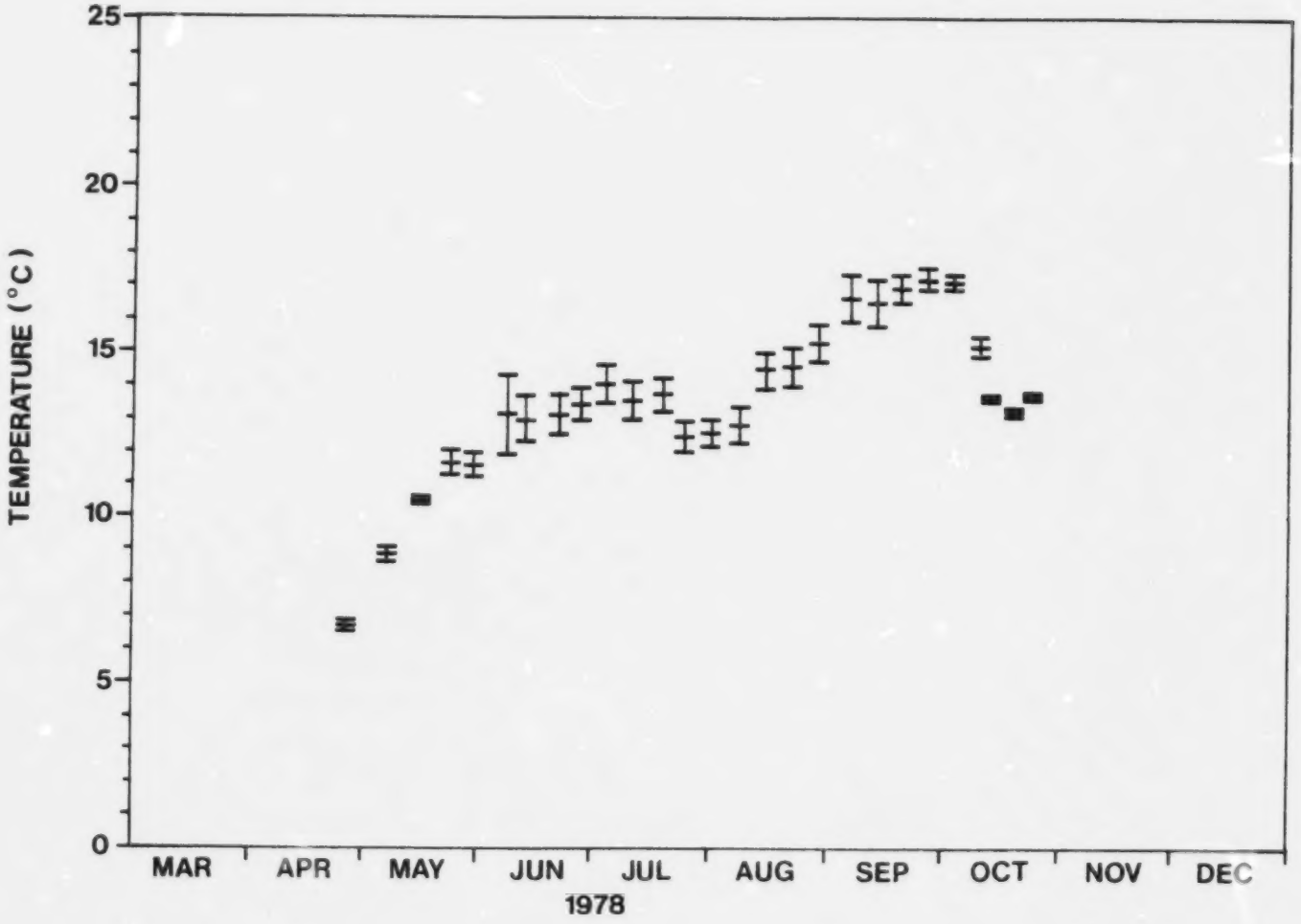

FIGURE 1.3b : OBSERVED TEMPERATURES FOR THE BOTTOM LAYER OF HAMILTON HARBOUR

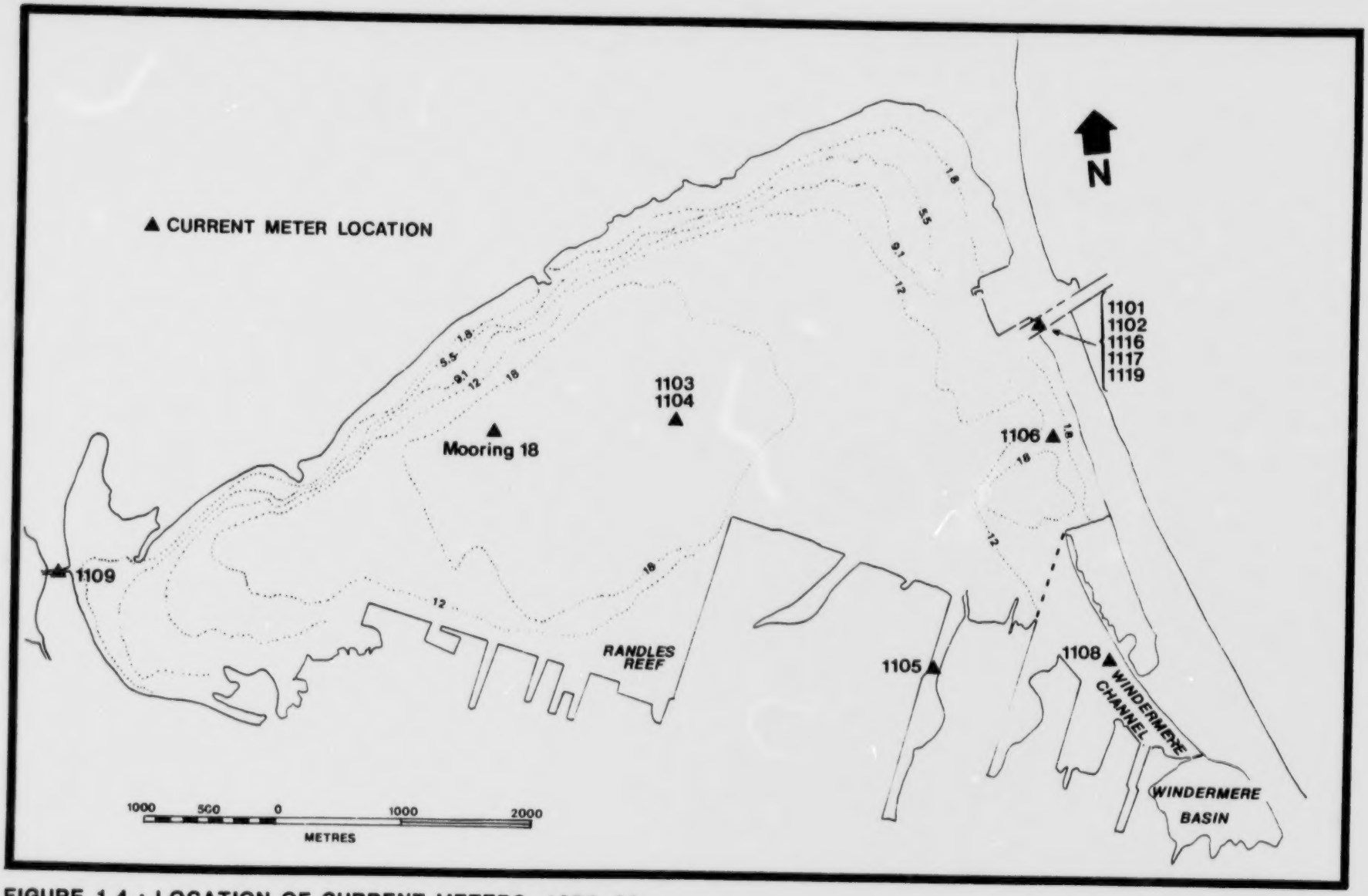

FIGURE 1.4 : LOCATION OF CURRENT METERS, 1972-80

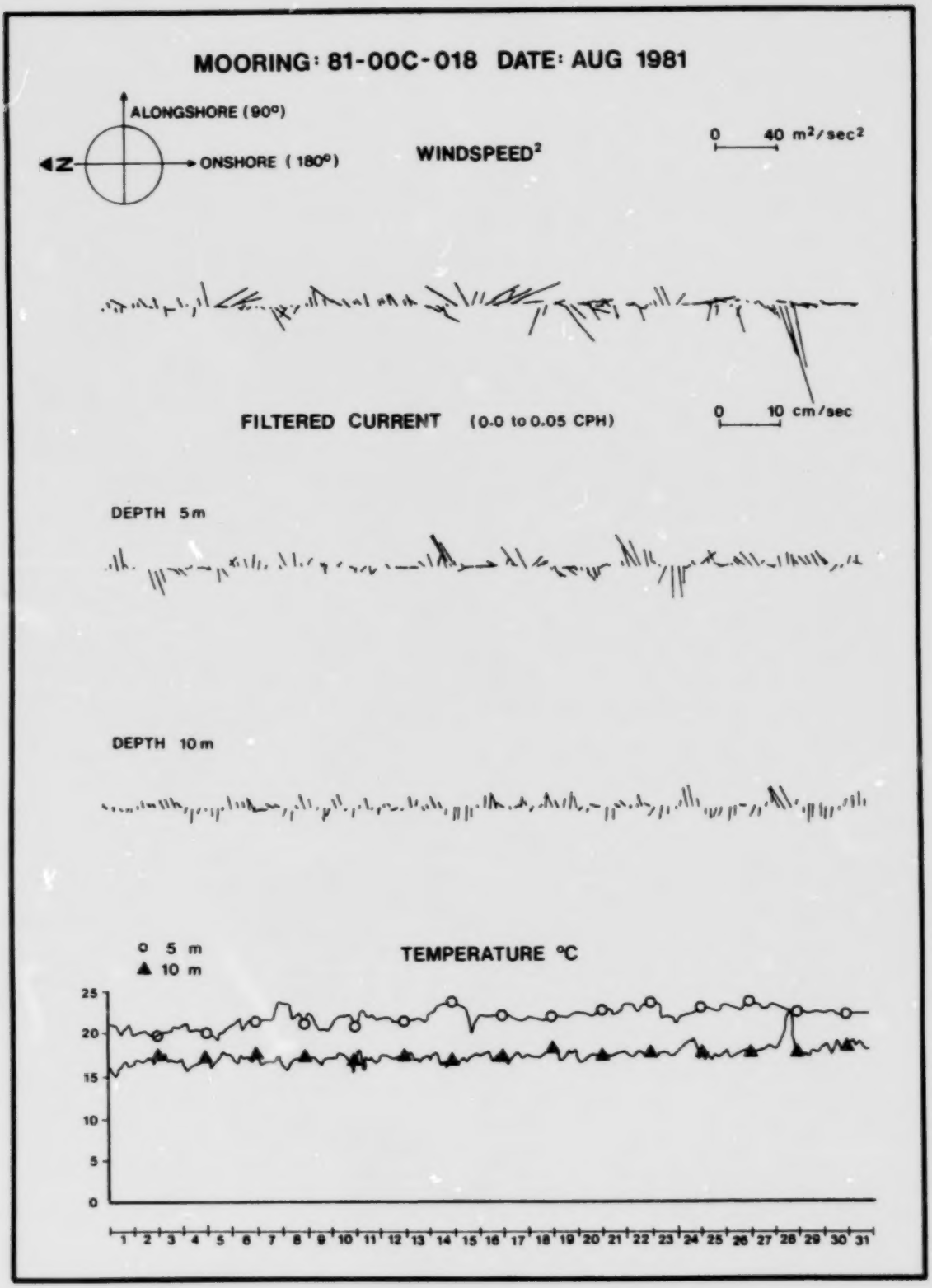

FIGURE 1.5 : CURRENT AND WIND VECTORS AT MOORING 18

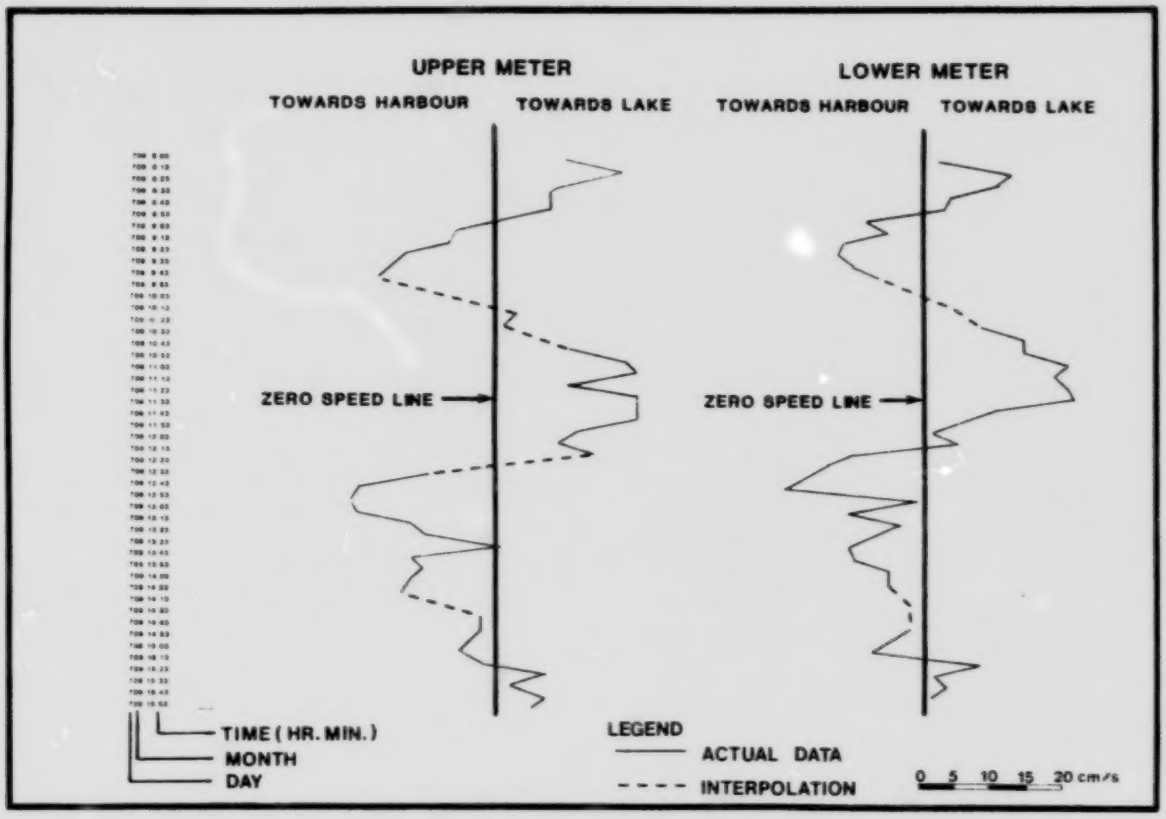

FIGURE 1.6 : TIME HISTORY OF CURRENTS RESOLVED ALONG BURLINGTON CANAL, LAKE ONTARIO, 1975

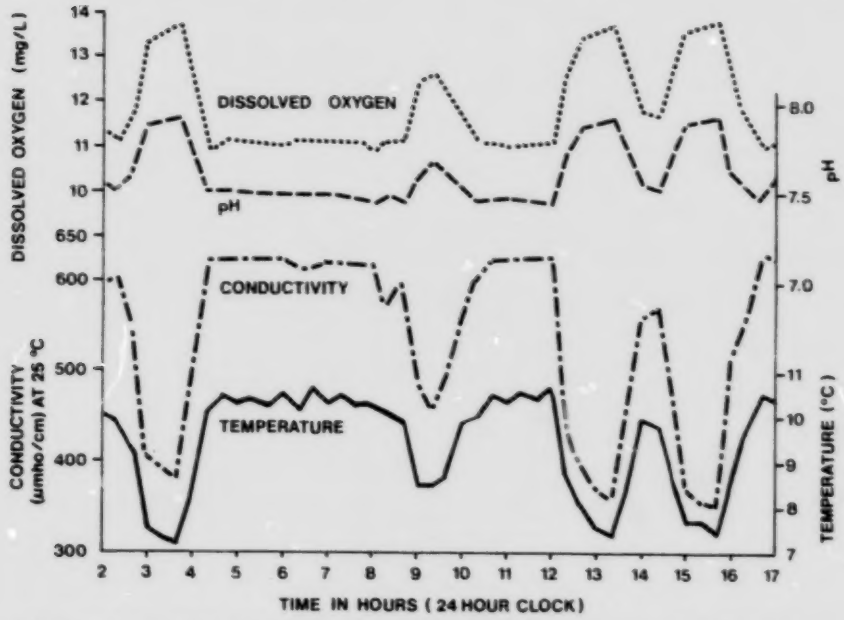

FIGURE 1.7 : WATER CHEMISTRY IN THE SHIP CANAL 6.7 m ABOVE THE BOTTOM FOR 1 MAY 1973 RECORDED DIGITALLY
(from Ont. Min. Environ., 1974)

2.0 LOADINGS TO THE HARBOUR AND TO THE LAKE

2.1 Loadings to the Harbour

2.1.1 Nutrients, BOD, Suspended Solids and Other Major Variables

2.1.1 a Municipal, Industrial, Tributary and Storm Overflows

As the harbour water quality is strongly influenced by the water inflows and outflows, especially exchange with the lake and by the nature and quantity of waste materials discharged to it, a knowledge of loading inputs is required for analysis of the present water quality status and estimation of the effects of abatement procedures. Estimates of pollutant loadings to Lake Ontario through the Burlington Ship Canal are also essential for proper assessment of the effect of Hamilton Harbour on Lake Ontario.

Estimates of pollutants loadings to the harbour between 1971 and 1977 were prepared by Snodgrass (1981 unpublished). Data for nutrients, BOD, COD, suspended solids (SS), dissolved solids, chloride, phenols, cyanide and several heavy metals are summarized in Table 2.1 and grouped by similar sources: the Hamilton and Burlington STP's, industries (Stelco and Dofasco), tributaries (Red Hill Creek, Grindstone Creek and Cootes Paradise), and stormwater runoffs from Hamilton and Burlington. Several minor tributaries draining to the north shore of the harbour are included with the Burlington stormwater runoffs. The locations of the sources are shown on Figure 1.1.

The errors and assumptions used in arriving at these figures have been discussed in detail by Snodgrass (1981 unpublished). For example, an uncertainty factor of four exists in the Cootes Paradise data: whereas Snodgrass estimated the flow as 394×10^3 m^3/d from hydraulic input data, current meters in the canal yielded the figure 95.6×10^3 m^3/d, which is probably an underestimate of the annual flow as the heavy-flow runoff period (March - April) was not monitored. The resultant uncertainty is important in assessing changes in the loading of several important parameters (BOD, COD, SS).

Harbour loadings for 1982 and for major sources in 1983 are summarized in Tables 2.2 and 2.3. The 1979 inputs from streams and nonpoint sources were also used in Table 2.2 to estimate the total 1982 loading, as these sources contribute a relatively minor portion of the total loads (Novak 1982).

The changes in municipal, industrial and combined loadings using 1977 as a baseline are shown on Table 2.4. From 1977 to 1979, there were significant increases in the municipal loadings of BOD, suspended solids, total phosphorus and iron. For the first two parameters the combined loadings did not change since the industrial loadings, which are greater than the municipal (Table 2.5), either decreased or stayed the same. While suspended solids loadings from the steel industries are large, this is due to the large water volumes. The average concentration of the final effluent is increased by 13 mg/L. The municipal loadings of total phosphorus make up more than 50% of the total phosphorus loadings to the harbour; therefore, changes in combined loadings parallel the municipal changes. Over 90% of the iron, phenolics and cyanide loadings came from industry; therefore changes in combined loadings reflect the changes in the industrial loadings. Nonpoint sources, which include Red Hill and Grindstone Creeks as well as Hamilton and Burlington stormwater runoff are minor contributors to the total loading in all cases.

Despite the increase in loadings in 1979, Table 2.4 reveals that, compared to 1977, the loadings in 1983 with the exception of total phosphorus have decreased by 40 to 80%. The increase in 1979 and subsequent decrease are reflected in the water quality of the harbour (see Section 3.0).

All of the loading data indicate that, to improve Hamilton Harbour water quality further, loadings from point sources (industrial and municipal), rather than from non-point sources, such as stormwater runoffs, have to be decreased.

2.1.1 b Atmosphere

Atmospheric loadings to the harbour (Kuntz unpub. data) were found to be below 0.5% of total loadings for all parameters except NO_3 and Pb, which were about 2% of total loadings. As these loadings were small in magnitude, they were not considered further. Similarly, possible releases from sediments have not been considered since there is no firm evidence for such releases in the harbour, with the possible exceptions of manganese and iron.

2.1.1 c Effects of Windermere Basin on loadings

Windermere Basin is a shallow (<1 m in depth), relatively small (0.4 sq. km.), artificially constructed basin situated at the southeast corner of Hamilton Harbour (Fig. 1.4). It was formed as a result of landfill reclamation projects between 1954 and 1972. The drainage area surrounding the basin is urbanized and industrialized. The Basin receives surface runoff via Redhill Creek and also from the land surrounding the Basin. Numerous combined sewer by-passes, storm sewers, and the Hamilton Sewage Treatment Plant discharge directly into Redhill Creek. Until 1981, the Hamilton Water Treatment Plant backwash water was also discharged to Redhill Creek. This water is now directed to the sewage treatment plant. The basin has served as a settling basin reducing the discharge of contaminated solids into Hamilton Harbour. However, because of the accumulation of deposited sediments (about 1 m in 20 years prior to 1976), large areas of sediments and debris are exposed during low water levels producing an aesthetically displeasing setting. The detention time for the basin is 1 to 2 days, depending on water inflow and the water level, that typically fluctuate 30 cm annually.

Surface water samples, taken at the inlet and outlet of the Basin during the summer months of 1977 and 1980 suggest that BOD, suspended solids, total phosphorus and total Kjeldahl nitrogen are still being deposited in the Basin (West Central Region MOE 1982). Consequently,

loadings to the harbour from the sources draining into the basin are less than (at least for the above variables) indicated in Tables 2.1, 2.2 and 2.3. Therefore, industrial loadings are relatively more important than indicated in Table 2.5.

2.1.2 Trace metals and trace organics

The loadings of trace metals in 1977 from all sources are given in Table 2.1. Loadings of trace metals from Stelco and Dofasco for the period 1977 to 1982 are given in Table 2.6a. The loadings for 1977 in this table are in very good agreement - a factor of two, except for chromium from Dofasco - with those in Table 2.1. Iron loadings for 1982 are in Table 2.2. There are no clear trends in the loadings of trace metals, except for the decrease in iron from both mills and for zinc from Stelco. This reduction in zinc can be ascribed to the recirculation of blast furnace scrubber water.

Total trace metal and trace organic concentrations in the effluents from the Hamilton and Burlington STP's were measured in 1982 and early 1983. Weekly trace metal loadings were calculated by multiplying the weekly average flow with the concentration. The loadings are given in Table 2.6b and compared with the 1977 loadings from Table 2.1. Since the concentration of Cd,Cr and Pb from both STP's and Ni from Burlington in 1982 were less than the detection limit, the values in the table represent the upper limits. Concomitant studies indicate that the metals are largely in the dissolved form, except for Fe and Cr, which appear to be mostly particulate (D. Poulton 1983).

Compared to 1977, the 1982-83 loadings for zinc and chromium and possibly copper, cadmium and lead are less at the Hamilton STP. The decrease may reflect reductions in loadings from industrial sources to the plant. At Burlington, the loading for iron has definitely increased and may have increased for copper. This increase is due to the use of ferric chloride for phosphorus removal since 1976.

A very limited program of measuring PCB concentrations in Red Hill Creek and the Strathearne St. stormwater outfall has been done. PCB's were seldom detected (sensitivity 0.02 ug/L) in Red Hill Creek. During runoff, PCB concentrations up to 0.05 ug/L were found. PCB's were consistently found at the Strathearne St. outfall, a previous transformer manufacturing site, at concentrations of 0.46 to 5.3 ug/L and as high as 180 ug/L in oil residues (MOE unpublished data). These data are in accord with finding the highest sediment PCB concentrations in the southeast part of the harbour.

Some hazardous contaminants were found in urban runoff from Hamilton in 1980 (Wang 1981). These included PCB's, organochlorine pesticides (OCP), PAH's, chlorinated benzene (CB) and heavy metals. The number of samples (1-5 per group) was too small to estimate loadings.

The loadings of the trace organics (pesticides and PCB's) from the Hamilton and Burlington STP's measured in 1982-1983 are given in Table 2.7a. No information is available on loadings of these compounds from industrial sources.

In 1978, single four-hour composite samples (7 in total) from the Hamilton STP and from specific Stelco and Dofasco waste streams were analyzed for polynuclear aromatic hydrocarbons (PAH's) (Smillie, et al. 1978). Approximately 40 PAH's were identified. The quantified PAH concentrations in the STP effluent ranged from 0.02 to 0.3 ug/L. Considerably higher concentrations were found in the coke plant effluents (1-24 ug/L), but since these are diluted by cooling water before discharge to the harbour, the final concentrations are in the same range as the STP effluent . Average final effluent concentrations are given in Table 2.7b as a comparison with PAH levels found in steel mills across the United States (EPA 1980). Statistical inferences may not be made in comparing these data; however, they are presented here to give a range of values. It should be noted that U.S. data include samples taken from indirect discharges which generally contain higher contaminant concentrations.

In 1982, further measurements of PAH's were done in the steel mill effluents (Zenon 1983). The laboratory intercomparison study that was part of this project showed reasonable agreement between analyses. Concentrations were generally less than 5 ug/L in the steel mill effluents and many compounds were not found to be present above the detection limit of 0.1 ug/L. Only naphthalene (0.2 ug/L) was detected in the Hamilton STP effluent. However, the results of this and other determinations by MOE suggest that the concentrations are quite variable. Because of the small number of samples, it is not possible to determine whether this variability is caused by sampling, differences in the analytical capabilities of the laboratories concerned, or whether it is real. Therefore, since reliable measurements are not available, it is not possible to calculate accurate loading values. As an example, calculated loadings of pyrene vary from 31 to 130 kg/year.

A study on organic and inorganic trace contaminants designed to measure the treatment process efficiencies and to determine the factors affecting contaminant removal in the Hamilton STP was done in 1983. Results published to date (Rush and Taylor 1983, Zukov et al. 1984) indicate that almost all (>94%) of the six PAH's measured (naphthalene, acenaphthylene, fluorene, fluoranthene, pyrene, benzo(a)pyrene) in the influent are removed. The resultant loadings to the harbour range from 4 to 84 kg/year. The PAH's end up in the treatment plant sludge. PAH's are preferentially adsorbed to particulate matter in water. However, at the concentrations of suspended matter found in the harbour, 60 to 95% of the total amount in a given volume of the harbour will be in the dissolved phase. PAH's are decomposed in the water column primarily through sunlight. The half-life of this process is of the order of hours. Settling particles carry the adsorbed PAH's to the sediment, where biological decomposition and burial occurs (IJC 1983). Therefore, because of the dilution of the effluents from the steel plants and the STP's and the removal processes, the concentrations in

the water column will be low (less than 100 ng/L), while high concentrations can be expected in the sediments. Ministry measurements indicate a concentration range of 1 to 10 ug/g in the sediments close to the discharges. Similar concentrations are found in other highly polluted areas such as Toronto or Buffalo.

2.2 Municipal and Industrial Pollution Measures

The Woodward Avenue sewage treatment plant began operation in 1963 as a 2.7×10^5 m^3/day (60 MGD) primary treatment facility. Conversion to secondary facilities was completed, and operations were begun late in 1973. In 1979, the capacity of the secondary section was increased 50% by construction of a 1.35×10^5 m^3/day (30 MGD) aeration section.

At present, the concentrations of BOD, suspended solids and total phosphorus, in the Hamilton STP discharge, are at or very near the Water Quality Objective levels required throughout the Province. Objectives have not been set for other parameters.

The Regional Municipality is currently redirecting, as much as possible, storm sewer overflows to the sewage treatment plant, resulting in less overflow of untreated sewage to the harbour.

All industries in Hamilton discharge their wastes to the sewage treatment plant; however, both Stelco and Dofasco discharge a portion of their waste directly to the harbour, after treatment. The majority of the industrial effluents were discharged to the STP immediately upon its completion in 1963. The few remaining industries were brought on line with the construction of the main interceptor sewers in the late 1960's.

At Stelco, clarifiers were constructed at the blast furnaces and later modified by installing recirculation systems. Blowdown from these systems is filtered to reduce suspended solids, zinc and cyanide in the discharges to the harbour. Ammonia recovery facilities and recirculation systems have been installed in the coke oven by-products areas to control ammonia, cyanide, phenolics and BOD_5 discharges. As

well, ammonia stripping facilities have been installed to remove ammonia from wastewater discharged to the municipal sewage treatment plant where phenolics, cyanide and BOD_5 are removed. Settling basins and filtration plants have been installed to remove suspended solids and oil from the wastewaters from the finishing operations. Other facilities installed include an oil treatment plant, ion exchange plant and acid regeneration plant to control oil, chromium and acid discharges, respectively. As well, a sanitary sewage collection system has been installed to prevent bacterial contamination of the harbour. The only remaining exceedences of the Ministry of the Environment existing objectives are phenolics in two of Stelco's effluents. Discharges from intermittent breakdown of equipment has been identified as one source and Stelco is under a Ministry Control Order to install indirect coolers and a recirculation system to eliminate this source. As well, studies are underway to identify and eliminate any other possible sources.

Dofasco has installed clarifiers to control suspended solids discharges from the blast furnaces and steel making furnaces. Indirect coolers and ammonia recovery facilities are used in the coke oven by-product areas to prevent phenolics, ammonia, cyanide and BOD_5 contamination of the harbour. Ammonia strippers and biological treatment have been installed to treat excess flushing liquor from coke ovens to control ammonia, phenolic, cyanide and BOD_5 discharges. A Zimpro process has been installed to eliminate a discharge containing high ammonia and thyiocyanate loadings. Dual media filters have been installed to control suspended solids and oil discharges from the hot strip mills. A wastewater treatment plant has been installed to treat wastes from other finishing operations to remove oil and suspended solids and provide neutralization. Other facilities installed include an acid generation plant and ion exchange plant to control discharges of acid and chromium, respectively. As well, Dofasco has installed a sanitary sewage collection system with connection to the Woodward STP.

Since 1967, the industrial loadings to the Harbour have been reduced as follows:

Parameter	1967 (kg/d)	1983 (kg/d)	% Reduction
BOD_5	33,000	4,300	86
Suspended Solids	150,000	25,300	83
Phosphorus as P	1,200	85	93
Ammonia as N	24,000	1,480	94
Cyanide as Cn	700	197	72
Phenolics	1,200	95	92
Solvent Extractables	25,000	1,480	94

With the completion of the programs being carried out by the steel companies under the Ministry of the Environment Control Orders, further small reductions in phenolics, cyanides and ammonia levels will take place.

2.3 Loadings to the sediments and to Lake Ontario

Loadings of phosphorus, BOD, COD and suspended solids to Lake Ontario were estimated by multiplying monthly harbour-wide average concentrations for May, 1979 to April, 1980 by the estimated total monthly flows to the lake, and summed to provide an annual loading. The results are given in Table 2.8. The fraction exported to Lake Ontario and that retained in the harbour was calculated from the mass-balance based on the loadings to the lake, the loadings to the harbour in Table 2.1 and reverse loadings from the lake to the harbour. The reverse loadings, estimated from Lake Ontario nearshore concentrations in the spring of 1979, and the exchange flows (Section 1.4) were about 5% of the total loadings to the harbour for P, and were not available (and probably insignificant) for the other parameters.

These calculations are valid on an annual average basis only, and assume steady-state conditions; i.e. no year-to-year change in harbour concentrations. Although the latter was not true for total P from 1977 to 1979, it was approximately correct for 1979 to 1980 (see Table 3.2). About 2/3 of the phosphorus input to the harbour is retained, presumably by sedimentation. This retention is less than average Great Lakes values (e.g. 78% for Lake Ontario), since the residence time in the harbour (90 days) is very short due to the flushing effect of the lake-harbour exchange.

Suspended solids largely settle out into the sediments. The retention figures for BOD and COD include utilization in the harbour either in the water column or the sediments. The BOD figure is a rough estimate because the harbour and loading BOD's were obtained by different methods and are not intercomparable. The fractions of COD exported to the lake is higher than that for BOD because COD represents a large number of compounds that are biochemically oxidized either very slowly or not at all. Because these remain in the water column longer, a larger fraction is exported to the lake.

The loadings of trace organics from the harbour to Lake Ontario in 1982-83 (Table 2.7a) were calculated by multiplying the average concentration in the water column (Table 3.6) with the flow to the lake (38.4 m^3/s; Table 1.1). This value represents the gross loading as the amount flowing into the harbour from the lake is not known. In any case, the amount contributed by the harbour to the lake is small compared to the loadings from the Niagara River and from the atmosphere.

Table 2.7a indicates that the loadings from the two STP's is considerably less than the export to the lake plus the amount sedimenting out. For some compounds, it is possible to obtain an indication of what the other sources could be.

The loadings to the sediments were calculated by multiplying the average concentration in the surface sediments (Table 3.10) by the total amount of material sedimenting out. The average measured sedimentation rate is 6.5 $g/m^2/d$. (M. Charlton NWRI unpub. data). The annual amount settling out, over the entire harbour, is $5.2 * 10^7$ kg.

As shown in Table 2.7a, the loadings of PCB's from the harbour to Lake Ontario is about 24 kg/year. In addition, the amount settling out within the harbour is 23 kg/year. Therefore, the total loading to the harbour is about 50 kg/year. Inputs from the Hamilton and Burlington STP's are about 5 kg/year. The loading from Red Hill Creek is about 1.5 kg/year (assuming a concentration of 0.05 ug/L). No information is available on the industrial loadings. As mentioned previously, the

concentration at the Strathearne Street outfall ranged from 0.5 to 5 ug/L. This is not typical of other outfalls, since it drains an area on which was previously located a transformer manufacturing plant. PCB's detected in Hamilton storm sewers by Wang (1981) are another possible input to the harbour. Extrapolation of this information to obtain loadings to the harbour is not possible.

The concentrations of PAH's on suspended particulates in the harbour range from <0.01 to 2.7 ug/g (Zenon 1984), for the same compounds studied by Zukovs et al. (1984). Assuming an average sedimentation rate of 6.5 g/m^2/year, the amount settling out ranges from 50 to 150 kg/y. Assuming an average suspended particulates concentration of 10 mg/L, the fraction on the particulates ranges from 2 to 10% (IJC 1983). For an outflow of $1.2*10^{12}$ L/y, the amount exported from the harbour ranges from 20 to 440 kg/y. The total loading to the harbour ranges then from 100 to 550 kg/y, depending on the compound. The loadings from the Hamilton STP make up 10 to 50% of the total load. The remainder comes from the steel mills and probably the storm sewers.

Identical calculations were done for the trace metals (see footnotes - Table 2.9 for information on sources used) and compared with similar work by Nriagu et al. (1983). The loadings to the harbour are within a factor of three. Nriagu et al. calculated the amount retained in the sediments and obtained the amount exported to the lake as the balance. This would explain the differences in these loadings. The loadings to the sediments are, except for Mn, within a factor of 2. Considering the assumptions, this agreement is excellent. In data obtained by the MOE, however, the amount sedimented out plus the amount exported is always less than the loadings to the harbour (except for Mn). The reasons for this discrepancy are not known; however, the data for loadings to the harbour are unreliable. Whichever set of loadings is used, the contribution of trace metals from Hamilton Harbour to Lake Ontario is small compared to the Niagara River and atmospheric contribution (refer to Table 2.7a).

2.4 Summary and conclusions

Although the best available information has been used in calculating loadings, the values given should be accepted with reservation.

1. The annual loading data to Hamilton Harbour (Tables 2.1a and b - 2.3) show that the Hamilton sewage treatment plant is the major source of phosphorus, ammonia and BOD to the harbour.

   While ammonia loadings decreased from 1977 to 1979, phosphorus loadings from the Hamilton STP increased and contributed to elevated harbour P levels. From 1979 to 1983, however, loadings have decreased significantly and are evident as changes in harbour concentrations.

2. The steel industries are the major source of iron, several other heavy metals, phenols, cyanide and suspended solids, while both industrial and municipal sources contribute similar quantities of COD. The loadings of many substances from the steel mills have decreased. This does not apply for metals, except for iron from both mills and zinc from Stelco.

3. The information available on the inputs of trace organics is not sufficient to determine the loadings from all sources, particularly the steel mills. The fragmented data suggested that storm sewers may be a source of PCB's and other organo-chlorines, while the steel mills and the Hamilton STP appear to be the major sources of polyaromatic hydrocarbons. Additional work is needed to address these issues.

4. Although the harbour acts as a sink for some of the inputs (Table 2.8), considerable amounts are exported out of the harbour (Tables 2.7a, 2.8 and 2.9). However, compared to the loadings from the Niagara River and the atmosphere, the harbour is a minor source of trace organics and trace metals to Lake Ontario (Table 2.9). This conclusion should be accepted with the caution that little data were available for the calculations of loads (e.g. the trace metal data in Table 2.9), and were not adequately quality assured.

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TABLE 2.1

ESTIMATED ANNUAL LOADINGS TO HAMILTON HARBOUR - 1977

Source	Flow ($10^3 m^3$/day)	Loadings (kg/day) BOD	COD	SS	TOC	TOTAL P	FRP	NH_3	NO_3	Fe
Hamilton STP	253.	5340	20000	11600	7870	326	192	10600	860	299
Burlington STP	56.9	910	3400	910	2300	45	27	460	140	7
Stelco	2.9*	5670	26600##	46000##	709#	78	0	1730#	-	21500##
Dofasco	-1.0*	2600	30200	30200	2458#	39	0	1750#	70	13000
Red Hill Creek**	83.4	1080	4400	7600	1700	67	13	78	95	18
Grindstone Creek**	82.7	500	2150	3300	1080	29	18	2	189	12
Cootes Paradise	345.	2700	15600	38000	1700	140	20	130	150	1100
Stormwater runoffs										
(a) Hamilton**	21.8	210	1600	1240	530	15	10	81	28	80
(b) Burlington	41.2	220	1100	1500	450	2	1	2	157	9
Total	884	19200	105000	140000	17800	740	280	15800	1700	36000

Note: Data from West Central Region, Ministry of the Environment.

* Net flows and loadings. Except for a small amount of effluent discharged to the Hamilton STP by Stelco, the two industries recirculate the water drawn from the harbour. Hence, net flows should be close to zero and values different from that are due to measurement error. A small negative value may result from evaporation during various quenching processes.

** A study done by Robinson et al. (1982) loadings of BOD, total phosphorus, total nitrogen (TKN + NO_3) and suspended solids to be for 1977.

\# Data from Environmental Protection Service, Environment Canada.

Calculated from concentrations provided by the industries.

TABLE 2.1 (Continued)

ESTIMATED ANNUAL LOADINGS TO HAMILTON HARBOUR - 1977

Source	Loadings (kg/day)									
	TDS	Cl	PHENOL	CYANIDE	Cu	Pb	Zn	Cd	Mn	Cr
Hamilton STP	135000*	39700	0	0	18	10.1	86	1.3	33	38
Burlington STP	-	45400	0	0	1	0	5	0	5	1
Stelco	258000*	6200	170##	1050##	110	15	990	0	350	31
Dofasco	-	14000	25	40	23	6.6	110	0	220	58
Red Hill Creek	96000*	6260	0.3	0	0.8	2.5	2	0.42	8	1.7
Grindstone Creek	-	11500	0.7	0	0.8	2.5	2	0.41	8	1.7
Cootes Paradise	11000	17000	0	0	7.6	10	23	1.8	88	7.0
Stormwater runoffs										
(a) Hamilton	7600*	990	1	1	0.7	1.5	9	0.1	8	1.1
(b) Burlington	-	6460	0.1	0	0.6	1.2	1	0.2	2	0.8
Total	420000	110000	200	1090	160	49	1200	4	720	140

Note *: Estimated by Snodgrass (1981) from conductivity data, combined as "municipal", "industrial", "surface streams" and "storm sewers".
Most zero values indicated as "assumed" by Snodgrass.
Calculated from concentrations provided by the industries.

TABLE 2.2

ESTIMATED ANNUAL LOADINGS TO HAMILTON HARBOUR - 1982

Source	Flow ($10^3 m^3$/day)	Loadings (kg/day) BOD	COD	SS	TOTAL P	FRP	NH_3	Fe	phenolics	cyanide
Hamilton STP	290.	3250	-	4930	333	203	8300	230**	-	-
Burlington STP	78.1	460	-	720	76	40	160	64**	-	-
Stelco	-46.@	5900#	17500	14500	-	-	910	6300	260	240
Dofasco	-13.@	780	20400#	16300	0	-	1540	4030	48	20
Others*	301.	1580	11220	10980	76	39	159	290	2	-
Total	610.	12000	-	47400	485	282	11100	10900	310	260

Note: Above loadings were calculated from data provided by the industries and STP's. Stelco and Dofasco data are net flows and loadings.

* 1979 data for Red Hill Creek, Cootes Paradise, and Hamilton and Burlington stormwater runoffs.

** D. Poulton, Hamilton Harbour 1982 Trace Contaminants report, Great Lakes Section (unpublished).

\# 1980 data, average of 5 to 6 months.

@ Net flow is negative due to consumptive loss.

\- No data available.

The non-point and combined sewer inputs are highly variable and loadings may exceed these estimates, especially for suspended solids.

Table 2.3

ESTIMATED ANNUAL LOADINGS TO HAMILTON HARBOUR IN 1983
FROM CERTAIN SOURCES[1]

Source	Loadings (kg/day) BOD	SS	Total P	NH_3	Phenolics	Cyanide
Hamilton STP	4300	3730	320	6890	-	-
Stelco and Dofasco	4380	25300	85	1480	95	197

1 Supplied by West-Central Region MOE.

- No data available.

Table 2.4

RELATIVE CHANGES[1] IN MUNICIPAL AND INDUSTRIAL LOADINGS OF SELECTED SUBSTANCES FROM 1977 TO 1983

Substance		Municipal[2]	Industrial	Combined
BOD	1979	1.73	0.75	1.17
	1982	0.59	0.81	0.72
	1983	0.76	0.53	0.63
Suspended Solids	1979	1.60	1.00	1.08
	1982	0.45	0.40	0.41
	1983	0.36	0.33	0.38
Total Phosphorus	1979	2.02	1.05	1.79
	1982	1.10	-	-
	1983	1.06	0.73	0.99
Ammonia	1979	0.45	1.29	0.65
	1982	0.77	0.70	0.75
	1983	0.64	0.43	0.59
Iron	1979	2.09	0.62	0.61
	1982	0.96	0.30	0.31
	1983	-	-	-
Phenolics	1979	*	0.60	0.60
	1982	*	1.58	1.58
	1983	*	0.49	0.49
Cyanide	1979	*	0.75	0.75
	1982	*	0.28	0.28
	1983	*	0.18	0.18

1 The loading for 1977 is taken as 1.00.
2 The 1983 loadings from the Burlington STP are assumed to be the same as the 1982 loadings.
* Signifies that there are no sizeable municipal loadings.
\- No data available.

TABLE 2.5

PERCENTAGE OF INPUTS TO HAMILTON HARBOUR FROM VARIOUS SOURCES IN 1977 and 1982

Sources	BOD	COD	SS	Total P	FRP	NH_3	NO_3	Fe	Phenol	Cyanide
1977										
Municipal	33	25	9	50	78	70	59	0.8	0	0
Industrial	43	49	55	16	0	28	4	96	99	100
Non-point*	10	10	9	15	15	1	28	0.3	1	0
Cootes Paradise	14	16	27	19	7	1	9	3	0	0
1982										
Municipal	31		12	84	86	76		3	0	0
Industrial	56		65	0	0	22		95	99	100
Others**	13		23	16	14	2		2	1	0

Note: * Non-point sources include Red Hill and Grindstone Creeks, Hamilton and Burlington storm runoffs. These data based on Tables 2.1, 2.2 and 2.3.

** Other sources include Red Hill and Grindstone Creeks, Cootes Paradise, Hamilton and Burlington stormwater runoffs (Table 2.2).

TABLE 2.6(a)

AVERAGE TRACE METAL LOADINGS (kg/d)
FROM STELCO AND DOFASCO, 1977-1983

	STELCO				DOFASCO			
Metal	1977	1979	1982	1983	1977	1979	1982	1983
Cu	44	46	8	82	18	-	0	1
Zn	1003	399	214	56	57	-	73	85
Mn	365	129	-	-	125	-	-	-
Cd	0	0	-	-	1	-	-	-
Cr	50	7	27	46	7	-	0	5
Pb	12	0	27	13	4	-	4	0
As	5	1	-	-	0	-	-	-

1. Loadings are net loadings. Supplied by West-Central Region, MOE. Loadings are calculated from arithmetic mean concentrations without discarding outliers. Individual waste streams were sampled (grab samples) 2 to 4 times per year.

Table 2.6(b)

AVERAGE TRACE METAL LOADINGS (kg/d) FROM THE HAMILTON AND BURLINGTON STP's, 1982-1983

Metal	HAMILTON		BURLINGTON		
	May-Sept. 1982	1977[2]	May-Sept. 1982	Jan.-Apr. 1983	1975[2]
Cu	9.5 (4.6)[1]	18	2.7 (1.1)	1.7 (0.4)	1
Ni	13 (6)	13	<1	0.4 (0.1)	2
Zn	21 (10)	86	7.0 (2.4)	8.6 (2.1)	5
Fe	230 (180)	299	64 (20)	61 (24)	7
Mn	24 (6)	33	3.5 (2.4)	6.8 (3.9)	5
Cd	<0.5	1.3	<0.2	0.5 (0.3)	-
Cr	<9	38	1	0.4 (0.4)	1
Pb	<7	10	<2	<0.4	-

1 Average (standard deviation). The number of samples in 1982 was 12 to 14; in 1983, around 15.

2 From Table 2.1. The loadings for Burlington are based on 1975 numbers.

- No data available.

Table 2.7(a)

LOADINGS OF TRACE ORGANICS TO HAMILTON HARBOUR FROM THE HAMILTON AND BURLINGTON STP's AND LOADING FROM THE HARBOUR TO LAKE ONTARIO (1982-1983)

Substance	Loading from:[1]		Loadings to Lake Ontario from:			Loadings to Sediment[5]
	Hamilton STP	Burlington STP	Hamilton Harbour[2]	Niagara River[3]	Atmosphere[4]	
	(kg/year)			(kg/year)		
Total PCBs	4.6	0.9	<24	3050	2300	23
α - BHC	0.5	0.1	5	1950	770	<0.1
β - BHC	0.4	0.1	<1	-	-	-
γ - BHC	1.8	0.4	10	400	3700	-
α - chlordane	<0.2	<0.1	-	42	-	0.3
γ - chlordane	0.3	<0.1	-	63	-	0.4
Mirex	1.9	0.6	-	28	-	-
DDT and Derivatives	<1.5	<0.1	-	61	-	-
HCB	1.4	1.1	<1.2	184	390	-
Dieldrin	-	<0.1	-	127	130	-
Oxychlordane	-	-	<2.4	-	-	-
Heptachlor epoxide	-	-	<1.2	<22	-	-
Endosulfan sulfate	-	-	<9.6	-	-	-

1 Calculated by multiplying average concentration by total annual flow:
Hamilton STP - $290 * 10^3$ $m^3/d = 1.06 * 10^8$ m^3/year
Burlington STP - $78.1 * 10^3$ $m^3/d = 0.285 * 10^8$ m^3/year.

2 Calculated by multiplying average concentration in the water column (see Table 3.6) with flow to lake (38.4 m^3/s from Table 1.1).

5 Calculated by multiplying average concentration on surface sediments (see Table 3.10) by total amount sedimenting out. The average measured sedimentation rate is 6.5 $g/m^2.d$ (M. Charlton, NWRI private communication). For a year, the amount settling out over the whole harbour is $5.2 * 10^{10}$ g.

3 From Kuntz and Warry (1983) for years 1979-1981.

4 IJC 1980 Annual Report - Table 3.

TABLE 2.7(b)
COMPARISON OF PAH CONCENTRATIONS IN EFFLUENT FROM
U.S. AND HAMILTON, ONTARIO STEEL MILLS (ug/l)

PAH	USEPA[a] Mean	USEPA[a] Range	MOE 1978[b] Range	MOE 1984[c] Range	MOE 1984[d] Range
Benz(a)anthracene	90	NA-2000	-	0.033*	-
Benzo(b)fluoranthene	28	NA-200	-	0.038-0.063	-
Benzo(k)fluoranthene	40	NA-360	0.04-1.0	0.028-0.041	-
Benzo(a)pyrene	21	NA-510	0.11-4.0	0.020-0.034	-
Indeno (1,2,3-cd) pyrene	7	NA	-	0.038-0.056	-
Dibenz(ah)anthracene	8	NA-16	<0.01	0.005-0.006	-
Benzo(ghi)perylene	16	NA	0.34-7.8	0.006-0.014	-
Acenaphthene	9	NA-53	-	-	0.7-1.5
Acenaphthylene	290	NA-6400	380*	-	5.0-16.1
Anthracene	91	NA-2800	360*	0.023-0.038	1.5-3.2
Chrysene	94	NA-2200	-	0.028-0.075	-
Fluoranthene	39	NA-3100	50*	0.191-0.275	ND
Fluorene	85	NA-2500	300*	-	3.1-7.1
Naphthalene	2300	NA-29000	370*	-	33.0-75.4
Phenanthrene	99	NA-2800	360*	-	4.6-8.4
Pyrene	79	NA-26000	50*	0.024-0.064	ND-2.1
Perylene	-	-	0.09-2.0	0.018-0.026	-

a) Source: 1980 EPA Treatability Manual Vol. 1: Data from Final Effluent and Process Stream Effluent
b) Source: Smillie et al. 1978: Final Effluent only.
c) Source: MOE 1984 unpublished data. Final Effluent only.
d) Source: Milgram 1984: Final Effluent only. Measurements performed by outside labs.
*) Single Sample analysis.
NA: Not Available
ND: Non-Detectable
-: Measurement not performed.

Table 2.8

LOADINGS TO LAKE ONTARIO FROM
AND RETENTION IN HAMILTON HARBOUR FOR 1979-1980

Parameter	Load to Lake Ontario from Harbour (10^6 kg/yr)	Load from Lake to Harbour (10^6 kg/yr)	Percent of Harbour Input Exported To Lake	Percent of Harbour Input Retained
Total P	0.122	0.017 (5%)*	34	66**
BOD	2.8	-	49	51
COD	26.	-	91	9
Suspended Solids	5.8	-	15	85

Note: * Bracketed Figure is percentage of total input from Table 2.1 that loads from lake represent.

** The amount of phosphorus sedimenting out of the water column based on sediment trap measurements in 1982 (M. Charlton NWRI 1982) is around $2.2 * 10^5$ kg/year. This represents 63% of the 1979 load and is greater than the 1982 or 1983 loadings to the harbour. The reasons for this discrepancy are not known.

- No data available.

TABLE 2.9

LOADINGS OF TRACE METALS TO THE SEDIMENTS IN HAMILTON HARBOUR
AND FROM THE HARBOUR TO LAKE ONTARIO

Metal	Loadings to: Harbour Sediments				Loadings to Lake Ontario from:			
	Harbour MOE[1]	Harbour NWRI[4]	Sediments MOE[2]	Sediments NWRI[4]	Harbour MOE[3]	Harbour NWRI[4]	Niagara River[5]	Atmosphere[6]
Cu	150	58	2	1.8	8.5	56	410	95
Zn	1200	438	29	45	23	395	610	948
Pb	49	18	3	6	6	12	200	379
Fe	36,000	13,100	760	880	194	14,100	79,400	632
Mn	720	260	110	18	180	240	<4,070	93

1 From Table 2.1

2 Sedimentation rate (6.5 $g/m^2/d$) *concentration at 0.2 m in suspended sediments at Station 258 in 1982 (Poulton 1983)

3 Concentration of Sta.258 in 1982 (Table 3.4) * flow out (38.4 m^3/s).

4 From Nriagu et al.1983

5 From Kuntz 1984.

6 From IJC 1980 Annual Report - Table 4.

3.0 WATER AND SEDIMENT QUALITY

3.1 Introduction

The Section is divided into two main parts - water quality and sediment quality. Each section is further subdivided into: conventional pollutants, trace metals and trace organics.

3.2 Water Quality and Comparison with Provincial Water Quality Objectives

3.2.1 Conventional water quality parameters

The water quality in the harbour was measured regularly, excluding the winter months, between 1975 and 1980 and again in 1983 at four major sampling stations and at several depths. Additional stations were sampled for special studies (Figure 3.1). Annual means and standard errors for many variables measured at these four stations are given in Table 3.1; these combine the results for all depths, stations and dates. The data for 1980 and 1983 are from station 258 only; however, an examination shows that the means, based on the four stations and station 258 only, are not statistically different.

A major factor controlling the water quality in the harbour is the loading from industrial municipal, tributary and storm sewer sources. The magnitude of the loadings is discussed in Section 2. The changes in loadings and water quality are compared in Table 3.2. Because of the short flushing time of the harbour (90 days) reductions in loadings should be reflected quickly by decreases in concentration. The loadings and concentrations are given relative to the assigned 1977 value of 1.00. As the table illustrates, changes in concentration may not closely parallel the changes in loadings due to the accuracy of both estimates. The best relationships exist for ammonia and total phosphorus.

The concentrations of some variables exceed the Provincial Water Quality Objectives on an occasional, seasonal or continuous basis (MOE 1984). Table 3.3 summarizes the exceedances of the Provincial Water Quality Objectives. Average levels of ammonia, zinc, and turbidity exceed the objectives. Iron, phenols and cyanide also exceed the objectives on an occasional basis. In addition, extremely low dissolved oxygen levels have been observed in the hypolimnion during the stratified period. (The oxygen problem is discussed further in Section 6.0 on the oxygen model.)

Water quality varies not only seasonally and from one year to the next, but also from one part of the harbour to another. One way of differentiating zones of similar water quality is through cluster analysis, in which the most closely related stations are grouped together. The analysis was performed on surface water quality data from 13 stations in 1980 and 17 stations in 1972. Means of four cruises for ammonia, total Kjeldahl N, $(NO_2 + NO_3)$ - N, total P, FRP, conductivity, chloride, turbidity, iron and chlorophyll a were used. The results are portrayed in Figure 3.2 for 1972 and Figure 3.3 for 1980. In both sets of data, station 20 represents by far the most distinct water mass. This location, closest to the Windermere Basin, was distinguished by higher values for nearly all parameters.

Aerial photographs of the harbour taken in 1980 show distinct coloured zones in the Ottawa Street Slip and at its mouth; in and at the mouth of Windermere Basin and in the corner near Randle's Reef. Depending on wind conditions, these zones can cover the whole of Windermere Channel and extend along the north and west sides of Stelco's property. Sediment plumes have been observed after periods of rain at the mouth of Grindstone Creek and extending past the Desjardins Canal to the harbour. Plumes of Cootes Paradise water are found near the Desjardins Canal and, on occasion, coloured zones have also been observed in the Strathearne Street Slip.

3.2.2 Trace metals

Trace metal concentrations were determined in 1982 on unfiltered water samples taken from 3 depths at stations 4, 258 and 270 and 2 depths at stations 20, 252 and 268 (Fig. 3.1). Samples collected on six occasions were analyzed for Cu, Ni, Zn, Cr, Pb, Fe and Mn; use of duplicate samples allowed a check of sampling and analytical variability as well as permitting the determination of interaction effects in an analysis of variance. Single samples only were analyzed for Hg, As and cyanide. In all cases, cyanide was below the detection limit of 5 ug/L; this parameter is thus not discussed further.

The average relative difference between duplicate samples for most metals was about 20%; for lead and iron, however, the differences were 45% and 30%. The high variability for lead was not surprising, as a large number of samples were below the detection limit. A possible reason for the high variability associated with iron could be variable amounts of suspended material in the pairs of samples (especially in bottom samples) as this metal was largely in the particulate phase. The three-way analysis of variance (station/depth/date) showed that most of the variation could be ascribed to differences between dates and that differences due to stations were next most important. Differences due to depth were not significant, except for manganese. The variation due to stations is caused by high values in the southeast part of the harbour (Station 20), close to the Hamilton STP and some of the steel mill outfalls (Poulton 1983).

The variation of manganese with depth is caused by its release from the sediment at the lower redox potentials that develop during the low oxygen or anoxic conditions during the summer and late fall. The release of manganese and, to a much lesser extent, of iron, was observed also in 1979. Weekly samples were collected from July to October in 1979 at station 258 and analyzed for the above metals. Depth-time distributions for manganese and iron are plotted in Figure 3.4. Although the iron data indicated no release from the sediments except briefly in late August, manganese was gradually released from

the bottom sediments, with the concentration reaching 1.2 mg/L in early October. After overturn, manganese concentrations rapidly dropped below 0.1 mg/L in the entire water column as oxidizing conditions reappeared (Poulton 1983).

No release of phosphorus from the sediments has been observed. Although manganese was released, the conditions were evidently not sufficiently reducing to release iron (except briefly) and hence phosphorus, which is bound to iron oxide. The inflow of oxygenated water onto the hypolimnion helps to stabilize the redox potential at a value sufficient to allow denitrification (reduction of NO_3 and NO_2) and manganese reduction but not low enough to allow iron reduction.

Although analysis of variance indicated that the largest proportion of variance was accounted for by between-date variations, inspection of cruise averages indicated that for most parameters the between-date variations were random; that is, there are no seasonal cycles. An exception was manganese, as already discussed. Consequently, the data were summarized by station in Table 3.4. In all cases except manganese and mercury, station 268 (nearest the Hamilton STP) had the highest average concentrations and percentages of Objective exceedances; station 20 in the Windermere Channel was next highest in most cases. Higher manganese averages (and standard deviations) at stations 4 and 258 reflect the increased bottom water concentrations at these stations during the summer as already discussed.

The parameter with the largest frequency of Provincial Water Quality Objective exceedances was copper, which exceeded Objective levels 66% of the time overall, and 100% of the time at station 268. This was followed by iron (29%), zinc (25%), cadmium (17%), nickel (3%), mercury (2%) and lead (1%). Arsenic did not violate objectives at any time. These findings may be contrasted with the limited data of 1975-80, which indicated that zinc nearly always exceeded objectives, while iron exceeded objectives most of the time at stations 4 and 20, and occasionally elsewhere. There has been a decrease in zinc concentrations from 1977-80 averages of 42-52 ug/L at station 258 to

the 1982 average of 19 ug/L. Although iron still exceeds objective levels most of the time at station 20, its average concentration has dropped from 0.80 $\pm$ 0.64 mg/L in 1979 to 0.41 $\pm$ 0.14 mg/L in 1982. This decrease is not statistically significant. The proportion of Objective violations, and average levels elsewhere in the harbour have both dropped since 1979 (Poulton 1983).

The 1982 harbour concentrations are compared in Table 3.5 with a single 13-station survey done in October 1980, and 1981 results from stations located in the southeast portion of the harbour (McIsaac, et al. 1982). Additionally, they are compared with some Lake Ontario values from 1978 (Nriagu, et al. 1981). The MOE data are presented as harbour-wide means and standard deviations, excluding stations 20 and 268. The table shows that copper, manganese, iron and zinc have decreased between 1980 and 1982, and that the concentrations in the harbour are 5 to 10 times higher than in Lake Ontario.

The relative proportion of particulate and dissolved trace metals in the water column was measured in 1982 on five dates. Because of experimental and analytical problems, valid information could be obtained only for zinc, iron and manganese. Zinc was 50 to 80% particulate at the surface and 20 to 40% particulate at the bottom. Bottom manganese was 95% particulate on June 19 and 25% particulate on October 8. This change is as expected, due to the accumulation of dissolved manganese under summer anoxia (Figure 3.4). After fall overturn, dissolved manganese was still present at very low levels, with bottom manganese being 50% particulate on November 24. Surface manganese varied from 65 to 95% particulate with no seasonal trend. Iron was about 90% particulate at the surface but varied widely at the bottom, being 20, 93 and 75% particulate on June 19, October 7, and November 24, respectively. This variation, if real, is not consistent with what would be expected for reduction of Fe(III) to Fe(II) as summer progresses, and its cause is unknown (Poulton 1983).

3.2.3 Trace organics

Surface water samples were collected six times at 6 stations in 1982 and analyzed for various trace organic compounds. For most compounds, the concentrations were below the detection limits. Table 3.6 gives the results for the compounds that were detected.

In both the sewage treatment plants discharging to the harbour and in the harbour itself, α and β-BHC (hexachlorocyclohexane) are the most commonly found of the organic compounds and are quite uniformly distributed throughout the harbour. However, the STP's may not be the only sources, since α-BHC is almost universally detected in Lake Ontario waters. It was found at a concentration of 3 to 4 ng/L in 5 out of 8 water samples analyzed in 1982 from the Burlington and Hamilton water intakes. Of the compounds examined, α-BHC was the only pesticide other than mirex to be detected at these locations. Kuntz and Warry (1983) found α-BHC in 100% of 75 water samples at Niagara-on-the-Lake in 1980-81, with an average concentration of 10 ng/L. Kauss (1983) also found α-BHC in most Niagara River water samples at an average concentration of 4 ng/L and suggested there was no local source of this compound because of its uniformity throughout the river system. Results obtained here indicate the same is true for Hamilton Harbour (Poulton 1983).

Only a very limited comparison of PCB-pesticide data with earlier (1975) results is possible. The only compound previously found with any regularity, endosulfan I, was not found at all in the harbour water or sediments. Lindane (γ-BHC) and PCB's were looked for but not found in 1975, although they were detected in 69% and 14% of the 1982 samples, respectively. All occurrences of PCB's in 1982 were at stations 20 and 268 near Hamilton STP and Redhill Creek, which were not sampled in 1975. Thus the results do not indicate a worsening problem. However, γ-BHC was found at the four major stations two-thirds of the time in 1982 at a median value of 1.0 ng/L. It is not known whether this is a result of improved analytical capability or whether it represents a new contamination. This compound was also generally present in the Niagara River (Kuntz and Warry 1983; Kauss 1983), though it was not found in the Burlington or Hamilton water works intakes in 1982. The other BHC's and HCB (hexachlorobenzene) were not determined in 1975. Other compounds were present too infrequently to warrant a comparison (Poulton 1983).

3.3 Sediment and Suspended Particulate Quality and Comparison with Provincial Guidelines for Dredged Sediment Disposal in Open Water

3.3.1 Conventional sediment quality variables and trace metals.

Means and standard errors of sediment data for major contaminants and trace metals representative of the top 3 to 7 cm are given in Table 3.7. The standard errors given are a measure of spatial variation with the highest contamination occurring in deep water (depositional area) and near the major outfalls, and low values being found in silty areas along the north shore and near the Burlington ship canal.

The contamination of the harbour sediments is indicated by the fact that from the averages in Table 3.7 all parameters except cobalt exceed MOE guidelines for the open water disposal of dredged material. Samples near outfalls exhibited specific enrichments for substances discharged in these areas. Table 3.8 summarizes the enrichments; in general, their location agrees with the sources of maximum heavy metal loadings. Included in the table are the pollutant concentrations measured in Windermere Basin sediments (West Central Region, MOE 1982), where high concentrations of nutrients, PCB's and almost all heavy metals were found. These substances come from the Hamilton STP, and stormwater/combined sewer overflow runoff from Red Hill Creek (Section 2).

Factor analysis of similarity coefficients derived from the ratios of sediment pollutant concentrations (1975 to 1980) was used to define areas of distinct sediment composition. All series provided similar zonations, which have been combined in Figure 3.3. A large zone of similar sediments, encloses the entire deep-water area of the harbour except the far east end. Pollutants have been gradually mixed and transported towards the deep central basins. Other distinct zones occur near the Burlington ship canal, where the effects of lake-harbour exchange are important, and along the north shore, where shallow-water silty sediments of lower pollutant concentrations are found. A variable area in the east end also occurs, which is apparently affected by harbour currents, discharges and lake exchange. Shallow locations close to the major outfalls (2, 262 and 268) represent individual zones related to the nearby discharges. Station 264 was also separated based on the effects of Cootes Paradise (MOE 1975).

The history of trace metal pollution is revealed in cores collected in the harbour in 1980 (Nriagu et al. 1983). The concentrations start to increase about 25 cm below the sediment-water interface. This depth likely corresponds to the onset of industrialization in Hamilton. The levels do not increase much until the uppermost 5 to 10 cm deposited since about 1950 according to Pb^{210} dates.

The formation, transportation and removal of particles through sedimentation controls the distribution of trace metals in water bodies. Because of their relatively long residence time in the water column, they can also play a significant part in regulating the chemical forms and hence the potential availability of metal ions in the water column.

The chemical forms of trace metals were determined on suspended sediments from the southeastern portion of the harbour in 1981 (McIsaac, et al. 1982) and at station 258 in 1982 between June and August (2 depths). The concentrations are given in Table 3.12 and compared with the sediment concentrations.

In all cases, at station 258, the samples from 0.2 m had considerably lower concentrations than those from 20 m, which were close to the sediment values, suggesting possible resuspension of bottom sediments. For manganese, however, the bottom suspended material was 5-15 times higher than the sediment values, possibly due to the oxidation and precipitation of dissolved manganese during sample processing. The values in 1981 and 1982 are not materially different and can be explained by the spatial and temporal variability of the harbour.

To assess the ease with which trace metals are released from the suspended material, the metals were fractionated into 5 groups, following the method of Tessier (1979). These are, in order of ease of exchange: exchangeable metal ions; surface oxide and carbonate-bound; Fe-Mn oxide bound; organically-bound; and residual.

Compared to studies in other locations (Gibbs 1977; Tessier et al. 1980) the Hamilton Harbour samples again show a greater contribution by organic and Fe-Mn oxide phases for many metals. This was particularly true for chromium, copper and zinc, as well as for iron for which the organic phase was generally second in importance to the residual phase. The difference can be attributed to the presence of large amounts of organic matter and iron compounds in the harbour and STP effluents. Tessier et al. (1980) also found large amounts of copper associated with organic matter at contaminated locations. The observed affinity of Cu for organic matter can be supported by the fact that for most ligands, copper has the highest stability constants of all the metals studied here (Stumm and Morgan 1970).

3.3.2 Trace organics

Analyses of trace organics in the sediments have been done over several years. Sediment samples were collected by dredge at 20 locations in 1975, and at 28 locations in 1978. Monthly sediment samples were also obtained at the four major sampling stations in June to September 1977. No changes in sampling techniques occurred in this program (Figure 3.1).

Sediment samples were collected by dredge in October 1982 from 20 locations. These were analyzed for PCB's and organochlorine pesticides, and samples from 6 locations (2, 20, 256, 258, 262 and 268) were also analyzed for polynuclear aromatic hydrocarbons. These locations were selected for their proximity to suspected discharge points or potential for deposition.

The percent of sediment samples having organic trace contaminants in detectable amounts is given in Table 3.9; median concentrations for those which were detected at least 50% of the time in 1982 are given in Table 3.10.

The most frequently detected contaminants were the PCB's (>80% of samples). As in previous years, concentrations varied widely from one location to another. However, no correlation exists between spatial patterns found in different years. Although most of the highest

concentrations in 1982 (>500 ng/g) were found in the deepest areas and along the industrial shoreline, the highest result (1270 ng/g) occurred at station 257 on the north shore, an area with historically low concentrations of most pollutants. On the other hand, station 268, near the outlet of Windermere Basin, was below detection limits. The analytical precision in PCB analysis is about ±10%; however, variations of an order of magnitude have been known to occur within a few metres in sediments (G. Rees pers. comm.). The reason for the apparently random variations in PCB levels in Hamilton Harbour sediments is presently unknown (Poulton 1983).

Of those tested, the most frequently occurring pesticides in 1982 were α- and γ-chlordane, and α-BHC, which were found in one-half to two-thirds of the samples. HCB, op-DDT, pp-DDE and β-BHC were found in 15 to 25% of the samples. No regular spatial distribution existed for any of these pesticides.

Because of the great spatial variability for PCB concentrations (and, presumably, for the other trace organic contaminants) and because in many cases most of the values are below detection limits, it is not possible to draw any firm conclusions about trends between years. However, the data for dieldrin and for DDT and its derivatives suggest a decrease in concentration from 1975 to 1982.

The concentrations in the sediments are considerably higher than in the surface waters (Table 3.6) since trace organics, by virtue of their chemical nature, tend to have an affinity for sediments. This affinity is often expressed as "partition coefficients" - the concentration on sediments/concentration in water; such partition coefficients may range from 10^4 upwards.

Summary results for the polyaromatic hydrocarbon analyses are given in Table 3.11. In all cases the maximum concentration was found at station 262 (Randle's Reef), and minimum concentration at station 20 (southeast harbour). For most compounds the order of stations from the

highest PAH concentrations to the lowest was 262 >2 >258 >268 >256 >20. This distribution pattern reflects an important source of these compounds - the steel mills. Hamilton STP effluents are not reflected as a source in the sediment concentrations (see Section 2). These concentrations are several orders of magnitude higher than levels found in the deeper portions of Lake Ontario (Onuska et al. 1983) but are similar to levels found in other polluted sediments such as near the Buffalo River (Black 1983).

Trace organic compounds, especially those of low molecular weight and simple structure, degrade quickly or disappear from the water through processes such as photolysis or evaporation. The degradation of persistent chlorinated compounds by microorganisms is generally slow as they do not act as growth substrates and are only incidentally transformed by the enzyme systems of the organisms. This process is called co-metabolism and leads to the accumulation of biologically stable chlorinated transformation products. It has also been found that, at low concentrations, the degradation rate is less than predicted because the concentrations are insufficient to induce the production of the necessary enzymes. The flora in eutrophic systems requires a higher minimum substrate for enzyme induction than in oligotrophic systems (Wood 1982).

Recent experiments have shown that desorption of PCB's and, presumably, similar persistent chlorinated compounds is made up of two types - a resistent fraction which is not resorbed as the aqueous concentration decreases, and a reversible fraction which is resorbed (DiToro and Horzempa 1982). Therefore, a fraction of adsorbed material will stay on sediments and suspended material. As an example, from the mean concentration of PCB's - 260 ng/g - in the sediments and a partition coefficient of 5×10^4 (Eisenreich et al. 1980), the concentration in the water phase is around 5 ng/L. The total concentration of the water column is then about 6.5 ng/L with approximately 20% in the particulate phase. The total amount in the water column is 2 kg and about 8 kg per year is exported to the lake (Table 2.7a gives a value for export of <24 kg). In contrast, the concentration in Lake Superior waters is

about 2.7 ng/L and only 3% is associated with the particulate phase. The mass in Hamilton Harbour sediment is possibly around 300 to 600 kg. Since the loading to the harbour is not known, the fraction retained cannot be calculated. About 23 kg/yr of PCB's end up in the sediments (Section 2).

Persistent organic compounds such as organochlorines are lipophillic and therefore partition between the aqueous and lipid phases in organisms with partition coefficients of the order of 10^3 to 10^5 (Eisenreich et al. 1980). Aquatic organisms can concentrate trace organics present at very low concentrations in the water column. For example, polynuclear aromatic hydrocarbons (PAH's) have been detected in effluents to the harbour from both the Hamilton sewage treatment plant and the steel mills, as well in carp and pike inhabiting the harbour at levels of - 100 ug/kg of fresh weight fillet (Hallett et al. 1978), although the concentrations on the harbour water are below the detection limit.

Some organochlorines affect growth and photosynthetic rates of phytoplankton, depending on the species, and, in higher biota, act as mutagens and carcinogens. Tumors have been found in fish living in the harbour. Approximately 40% of the white suckers caught in Hamilton Harbour have lip papillomas (IJC 1983, Fig. 6-2).

The concentrations of PCB's, mercury, mirex and DDT in fish caught in the harbour are sufficiently low to make them generally suitable for human consumption. The levels measured in the lean, dorsal muscle tissue are less than 0.5 ug/kg of mercury, 2.0 for PCB's, 5.0 for DDT and 0.1 for mirex. These values represent the Federal guidelines for fish consumption (MOE 1983).

3.4 Summary and Conclusions

1. Concentrations of the nutrients and other water quality (Table 3.1) variables show a rise from 1975 to 1977, followed by a drop that is still continuing. The cause is the decrease in loadings to the harbour, although the concentration decrease is not as rapid as the

change in loadings. There is also a decrease in the concentrations of iron, zinc, manganese and copper between 1980 and 1982. This decrease is reflected in the concentrations in the top layer of the sediments. There is not enough information about trace organics in the water or in the sediment column to detect any trends.

2. Average levels of ammonia, zinc and turbidity exceed the Provincial Water Quality Objectives. Iron and phenols also exceed the Objectives occasionally. In addition, extremely low dissolved oxygen levels have been observed in the hypolimnion during the stratified period.

3. The sediments with the highest contamination levels are found in the deep water depositional area and near the major outfalls. Relatively uncontaminated sediments are found in the silty areas along the north shore and near the Burlington ship canal. The average sediment concentrations of almost all parameters, including trace metals, exceed Ministry of the Environment Guidelines for the open water disposal of dredged material.

4. There is very little information on the fate of trace metals and trace organics or on their effect on the biota in the harbour. The levels of mercury, PCB's, DDT and mirex measured in fish from the harbour meet guidelines for fish consumption.

5. Over 80% of the loadings of suspended solids into the harbour are retained in the harbour (Section 2). Therefore, the trace contaminants associated with these particulates will also be retained and settle out to the bottom. Although high molecular weight trace organics are strongly adsorbed to particulates in the water column, most of the total mass of organics is in the dissolved phase because of the relatively low concentration of particulates. For example, in the case of PCB's, only 20% is associated with the particulate fraction. Therefore, more is exported from the harbour than settles to the bottom. There is little evidence for the release of trace metals from the sediments. The exceptions are Mn and Fe which may be released from the sediments under anoxic conditions in the summer.

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Table 3.1

HARBOUR-WIDE MEANS FOR WATER QUALITY PARAMETERS - ANNUAL

UPPER NUMBER - MEAN
LOWER NUMBER - STANDARD ERROR

PARAMETER	1975	1976	1977	1978	1979	1980	1983
NH3-N	1.26	1.43	1.95	-	1.26	1.21	1.13
	0.056	0.059	0.116	-	0.063	0.123	0.068
TKN	2.25	2.07	2.65	-	2.26	2.04	1.76
	0.064	0.058	0.117	-	0.083	0.142	0.051
NO2-N	0.21	0.16	0.14	-	0.19	0.23	0.17
	0.014	0.005	0.005	-	0.005	0.029	0.020
NO3-N	1.74	1.64	1.62	-	2.09	2.18	1.41
	0.037	0.027	0.038	-	0.023	0.060	0.051
TOTP	0.076	0.057	0.064	0.080	0.104	0.081	0.056
	0.0020	0.0012	0.0017	0.0019	0.0028	0.0032	0.0025
FRP	0.014	0.013	0.018	0.027	0.043	0.031	0.014
	0.0008	0.0005	0.0009	0.0009	0.0019	0.0027	0.0008
Si	0.64	0.40	0.51	0.50	0.50	0.46	-
	0.022	0.014	0.027	0.029	0.033	0.043	-
BOD	4.20	3.61	3.39	3.34	3.17	2.33	3.09
	0.243	0.213	0.128	0.124	0.110	0.187	0.117
COD	-	20.6	28.8	26.6	20.9	20.0	15.7
	-	0.59	1.29	0.66	0.63	1.65	0.48
TOC	6.92	5.82	6.54	3.37	3.66	-	-
	0.190	0.208	0.169	0.032	0.046	-	-
FOC	-	5.05	5.96	-	-	3.77	3.2
	-	0.206	0.208	-	-	0.068	0.04
COND	493.	521.	515.	499.	532.	522.	424.
	2.7	3.5	4.7	4.6	4.3	7.6	7.3
ALK	100.	106.	105.	104.	103.	104.	-
	0.5	0.6	0.9	0.9	0.7	1.0	-

..... Continued

- No Data Available

Table 3.1 (Continued)

HARBOUR-WIDE MEANS FOR WATER QUALITY PARAMETERS - ANNUAL

UPPER NUMBER - MEAN
LOWER NUMBER - STANDARD ERROR

PARAMETER	1975	1976	1977	1978	1979	1980	1983
pH	7.84	7.94	7.87	7.96	7.88	7.83	-
	0.025	0.018	0.025	0.022	0.018	0.039	-
SO4	56.6	-	-	-	55.5	53.1	51.2
	1.23	-	-	-	0.55	0.97	0.79
Cl	57.2	-	-	-	-	55.5	50.4
	1.14	-	-	-	-	1.24	0.93
TURB	2.19	3.34	3.03	3.08	2.86	2.65	-
	0.061	0.127	0.070	0.093	0.095	0.233	-
SS	-	5.76	5.72	5.80	5.33	4.68	-
	-	0.140	0.160	0.276	0.190	0.326	-
Fe	0.28	0.32	0.29	0.22	0.25	0.25	0.22
	0.011	0.015	0.014	0.009	0.014	0.038	0.036
Zn	-	0.089	0.046	0.043	0.046	0.052	-
	-	0.0047	0.0011	0.0016	0.0013	0.0077	-
CHL A	16.7	17.1	-	13.6	18.2	13.6	14.5
	0.65	0.57	-	0.50	0.90	1.10	0.65
Approximate number of observations	360	275	200	275	220	22	160

The means for 1975 to 1979, inclusive, are calculated from data for stations 270, 258, 252 and 4. In 1980 and 1983, data from 258 only was used.

Table 3.2

COMPARISON OF CHANGES IN LOADINGS TO THE HARBOUR* AND CONCENTRATIONS IN THE HARBOUR** SINCE 1977

SUBSTANCE	1978	1979	1980	1982	1983
Ammonia					
a - relative loading+	-	0.65	-	0.75	0.59
b - relative concentration	-	0.65	0.62	-	0.58
Total Phosphorus					
a	-	1.79	-	-	0.99
b	1.25	1.63	1.27	-	0.88
Suspended Solids					
a	-	1.08	-	0.41	0.38
b	1.01	0.93	0.82	-	-
BOD					
a	-	1.17	-	0.72	0.63
b	0.99	0.94	0.69	-	0.91
Iron					
a	-	0.61	-	0.31	-
b	0.76	0.86	0.86	-	0.76

NOTES:
* From Table 2.4 ; Loadings from Industrial and Municipal Sources only
** Calculated from Table 3.1
\+ 1977 is taken as 1.00
\- No Data Available

TABLE 3.3

PERIODS OF VIOLATION OF PROVINCIAL WATER QUALITY OBJECTIVES*

PARAMETER	OBJECTIVE**	WHEN VIOLATED
Ammonia (as N)	0.02 (unionized)	surface: winter to August bottom: winter to June
Dissolved Oxygen	Varies with temperature and biota	June to September in bottom waters
Total phosphorus	0.02***	All year
Turbidity	No more than 10% decrease in ambient Secchi disk	All year
Phenols	1 ug/L	Occasionally
Cyanide	0.005	Occasionally
Zinc	0.03	Nearly always
Iron	0.3	Most of the time at stations 4 and 20; occasionally in other areas.

Note: * For the protection of aquatic life
** Values are in mg/L unless otherwise noted (MOE 1984)
*** Only a general guideline; no firm objective exists.

TABLE 3.4

SUMMARY STATISTICS OF HEAVY METAL DATA BY STATION, HAMILTON HARBOUR, 1982 (ug/L)*

Station		Cu	Ni	Zn	Cd	Pb	Fe	Mn	Hg	As
4	Median	7	5	20	<0.2	4	210	52	.04	1
	Min.	1	2	10	<0.2	<3	20	17	.03	<1
	Max.	20	11	116	0.6	31	1000	760	.26	3
	% below D.L.	0	0	0	69	31	0	0	44	44
	% above PWQO	56	0	17	14	3	28	-	3	0
20	Median	8	7	32	<0.2	6	390	59	.08	1
	Min.	3	4	19	<0.2	<3	180	34	<.03	<1
	Max.	14	12	41	0.5	12	660	92	.25	1
	% below D.L.	0	0	0	54	25	0	0	25	25
	% above PWQO	67	0	58	21	0	75	-	8	0
252	Median	7	5	18	<0.2	4	170	39	.10	<1
	Min.	2	<1	2	<0.2	<3	20	22	<.03	<1
	Max.	17	10	50	0.9	11	790	91	.16	1
	% below D.L.	0	8	0	67	42	0	0	25	50
	% above PWQO	71	0	8	25	0	8	-	0	0
258	Median	7	5	16	<0.2	4	150	47	.07	<1
	Min.	<1	2	10	<0.2	<1	52	17	<.03	<1
	Max.	40	17	44	0.4	10	460	880	.21	1
	% below D.L.	6	0	0	78	53	0	0	22	67
	% above PWQO	61	0	11	14	0	11	-	3	0

.... Continued

- No Data Available

TABLE 3.4 (Continued)

Station		Cu	Ni	Zn	Cd	Pb	Fe	Mn	Hg	As
268	Median	10	16	38	0.2	9	400	97	.07	1
	Min.	6	9	21	<0.2	<3	224	52	.04	1
	Max.	33	38	129	1.7	30	2100	120	.20	2
	% below D.L.	0	0	0	42	8	0	0	0	0
	% above PWQO	100	23	82	32	5	68	-	0	0
270	Median	7	5	16	<0.2	2	170	43	.06	<1
	Min.	2	1	11	<0.2	<3	70	17	<.03	<1
	Max.	30	7	36	0.4	10	350	140	.20	1
	% below D.L.	0	0	0	81	50	0	0	28	61
	% above PWQO	58	0	3	6	0	8	-	0	0
Detection Limit (D.L.)		1	1	1	0.2	3	3	1	.03	1
PWQO		5	25	30	0.2	25	300	-	0.2	100

Note: Number of data points = 36 for each metal, except 18 for Hg, As at stations 4, 258, 270
= 24 for each metal, except 12 for Hg, As at stations 20, 252, 268.

*Table from Poulton 1983.

TABLE 3.5

TRACE METAL CONCENTRATIONS* IN
HAMILTON HARBOUR AND LAKE ONTARIO

METAL	HARBOUR**			LAKE ONTARIO***
	1980	1981	1982	1978
Cu	31 (21)	1.96 (0.43)	7 (5)	1.3 - 1.6
Cd	0.3 (0.2)	0.14 (0.03)	0.2 (0.1)	0.051 - 0.058
Cr	<1	0.66	-	-
Pb	7 (3)	3.1 (0.61)	5 (3)	<0.27 -<0.41
Ni	4 (1)	-	5 (2)	0.9 - 1.12
Mn	73 (10)	-	39 (13)	-
Fe	300 (60)	-	200 (130)	-
Zn	46 (18)	-	20 (12)	-

* All concentrations are given in ug/L.
** 1980 and 1982 data collected by MOE; 1981 by McIsaac, et al. 1982. Mean and standard deviations (in brackets) are shown.
*** 1978 values from Nriagu et al. 1981. Values given show the range.
\- Data not available.

TABLE 3.6

PCB's AND ORGANOCHLORINE PESTICIDES IN HAMILTON HARBOUR SURFACE WATERS, 1982, ng/L

Parameter	Median	Max.	Min.	% of Samples >Detection Limit	% Exceeding Objectives
Total PCB	<20	30	ND	14	14
α - BHC	4.5	6	ND	92	-
β - BHC	<1	3	ND	14	-
γ - BHC	3	59	ND	69	14
Endosulfan sulfate	<4	4	ND	3	-
Heptachlor epoxide	<1	1	ND	3	0
Oxychlordane	2	4	ND	6	-
HCB	<1	4	ND	25	-

Note:
1. Total number of samples = 36
2. ND = none detected
3. The following were not detected at any time: aldrin, α- and γ- chlordane, dieldrin, methoxychlor, endosulfan I and II, endrin, heptachlor, mirex, DDT and its metabolites.

\- No Provincial Water Quality objectives.

TABLE 3.7

MEAN RESULTS OF HAMILTON HARBOUR SEDIMENT ANALYSIS, 1975-80

	May 1975		June 1976		May 1977		October 1977		October 1980		MOE guideline for dredged sediment disposal
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
LOI (%)	10.5	1.4	-	-	9.1	1.0	9.5	1.9	9.8	2.2	6
BOD (mg/g)	3.9	0.8	-	-	-	-	2.6	0.4	-	-	-
SOD (mg/g)	152.	20.	140.	20.	150.	24.	150.	18.	-	-	50
NH_3	-	-	-	-	30.	4.	10.	1.2	-	-	100
TKN (mg/g)	3.5	0.5	2.7	0.3	2.9	0.4	2.9	0.3	3.5	0.4	2.
Total P (mg/g)	3.4	0.4	2.4	0.3	2.7	0.4	2.9	0.3	3.2	0.5	1.
Acid Ext. P(mg/g)	2.3	0.2	-	-	-	-	-	-	-	-	-
Ether Ext. (mg/g)	-	-	-	-	12.5	3.0	7.6	1.2	-	-	1.5
Fe (mg/g)	68.	9.1	70.	13	88.	22	-	-	68.	12.	10.
Cu	101.	13.	-	-	-	-	110.	18.	130.	18.	25.
Cr	206.	34.	200.	37.	-	-	220.	40.	204.	38.	25.
Ni	45.	4.1	39.	5.	-	-	52.	7.4	44.	4.	25.
Zn	3110.	447.	2010.	349.	2600.	440.	-	-	2700	380.	100.
Pb	320	45.	260.	43.	310.	58.	300.	40.	310.	45.	50.
Cd	7.8	1.1	5.0	0.7	-	-	6.3	0.8	5.7	0.8	1.
Mn	1670.	373.	-	-	-	-	-	-	1900.	224.	-
Hg	2.4	0.5	0.4	0.1	0.7	0.1	0.6	0.1	0.3	0.04	0.3
Co	15.	1.	-	-	-	-	12.	0.8	10.	0.9	50.
As	-	-	-	-	19.	3.0	22.	3.	-	-	8.
Number of Samples	20		26		25		25		20		

Note: Samples for May, 1975, and May and October, 1977 taken by Ekman dredge. Samples for June 1976 and October 1980 taken by Phleger corer, and top 5-7 cm (1976) or 3 cm (1980) subsampled for analysis. All values in ug/g (dry weight basis) unless otherwise stated.

- No data available.

TABLE 3.8

SHALLOW ZONES EXHIBITING HIGHEST SEDIMENT POLLUTANT CONCENTRATIONS, HAMILTON HARBOUR, 1975-80

Location	Parameter with elevated concentration**	MOE guideline concentrations** for dredged sediment disposal	Observed Concentration
268 (Hamilton STP)	TKN	2 mg/g	8-11 mg/g
	Total P	1 mg/g	5-10 mg/g
	Ether Ext.	1.5 mg/g (Oil & Grease)	25 mg/g
	Cu	25	170-340
	Cr	25	250-700
	Ni	25	40-80
	Hg	0.3	0.24-0.68
	Pb	50	140-460
	Zn	100	700-2400
	Cd	1.0	2.4-7.6
	PCB	50	200-1800
Windermere Basin	TKN	2 mg/g	13-29 mg/g
	Total P	1 mg/g	13-24 mg/g
	Cu	25	500-800
	Cr	25	1070-1300
	Hg	0.3	1.6-3.4
	Pb	50	700-1100
	Zn	100	3400-5200
	Cd	1.0	12-18
	PCB	50	10,000
20 (Between Hamilton STP and Dofasco)	TKN	2 mg/g	4-5 mg/g
	Total P	1 mg/g	4.5-6 mg/g
	Cr	25	300-500
	Cd	1	6-8
	Hg	0.3	0.5-1.4
2 (inside Ottawa St. slip)	Ether Ext.	1.5 mg/g	20 mg/g
	Fe	10 mg/g	250-450 mg/g
	Cu	25	200-400
	Cr	25	300-1200
	Ni	25	60-190
	Zn	100	3500-8400
	Pb	50	330-1000
	Mn	-	3200-4500
	Hg	0.3	0.7-1.2
	As	8	45-60
256 (mouth of Ottawa St. slip)	Ether Ext.	1.5 mg/g	20-40 mg/g
	Fe	10 mg/g	80-170 mg/g
	Cu	25	100-180
	Cr	25	230-670
	Mn	-	1500-3200
	Hg	0.3	0.2-1.2
	As	8	50
262 (Randles Reef)	Ether Ext.	1.5 mg/g	70 mg/g
	Fe	10 mg/g	90-140 mg/g
	Zn	100	4600-7800
	Pb	50	500-1200
	Cd	1	7-12
	Mn	-	2200-2400
	Hg	0.3	0.2-2.7
270 (SW corner)	Cd	1	10-12

** All concentrations in ug/g dry weight basis unless otherwise stated.
- No data available.

TABLE 3.9

TRACE ORGANICS DETECTED IN HAMILTON HARBOUR SEDIMENTS AS PERCENT OF SAMPLES ANALYZED PER YEAR

Compound	1975	1977	1978	1982	Detection Limits in 1982 (ng/g)
PCB's	100	100	89	85	20
Lindane	0	14	11	0	1
Heptachlor	0	0	0	0	1
Aldrin	0	0	0	5	1
Dieldrin	30	14	4	0	2
Endrin	15	0	0	0	4
Heptachlor epoxide	0	0	0	0	1
pp'-DDE	0	57	68	25	1
pp'-DDD	95	50	57	0	5
op'-DDT	65	7	4	15	5
α - chlordane	55	50	0	55	2
γ - chlordane	-	50	11	65	2
Thiodan - I	-	7	0	0	4
Thiodan - II	-	0	0	0	4
HCB	-	43	4	25	1
α - BHC	-	29	7	50	1
β - BHC	-	21	7	15	1
Mirex	-	0	11	0	500
Number of samples analyzed each year	20	14	28	20	-

- No data available.

TABLE 3.10

CONCENTRATIONS OF PCB's AND ORGANOCHLORIDE PESTICIDES IN HAMILTON HARBOUR SEDIMENTS IN OCTOBER 1982

Compound	Median (ng/g)	Range*	% of Samples > Detection Limit
Total PCB's**	200	20 - 1270	85
α - BHC	1	1 - 6	50
α - Chlordane	2	2 - 18	55
γ - Chlordane	4.5	2 - 20	65

NOTES: * The first number is the detection limit.
** Peaks resemble a 4:1 mixture of Aroclor 1254 and 1260 commercial mixtures, except at 3 stations, where it is mostly 1260.

TABLE 3.11

POLYNUCLEAR AROMATIC HYDROCARBONS IN
HAMILTON HARBOUR SEDIMENTS
1982

Compound	Range (ug/g)*
Fluoranthene	1.9 - 4.3
Perylene	1.2 - 9.7
Benzo(k)fluoranthene	1.1 - 9.0
Benzo(a)pyrene	1.2 - 11.1
Benzo(g,h,i)perylene	1.6 - 8.6
Indene (1,2,3 cd) pyrene	1.1 - 9.7

* Number of Samples = 6

TABLE 3.12

TOTAL METAL CONCENTRATIONS IN SUSPENDED PARTICULATE MATTER FROM HAMILTON HARBOUR

Units in ug/g except where noted

Element	Suspended Sediment		Bottom Sediment	
	Mean[1] ± S.E. Windermere Channel, 1981	St. 258[2] 1982	St. 258[3] (0.1 cm)	Windermere[4] Basin 0-5 cm Average Content
Al (mg/g)	1.80 ± 0.84	-	-	-
Cd	16 ± 0.5	-	5.7	12
Co	18 ± 0.5	22 ± 9	15	-
Cr	265 ± 9	144 ± 51	204	1070
Cu	140 ± 0.7	103 ± 30	130	500
Fe (mg/g)	2.95 ± 0.7	35 ± 9	68	42
Mn (mg/g)	8.1 ± 0.7	20 ± 9.5	1.9	-
Ni	110 ± 10	50 ± 14	66	-
Pb	365 ± 12	192 ± 86	310	700
Zn	1970 ± 91	1050+ 227	2700	-

1. No. of samples = 34; McIsaac et al. 1982.
2. No. of samples = 6; Poulton 1983.
3. Data from Table 3.7 for October, 1980.
4. Data from Ontario Ministry of the Environment
- No data available.

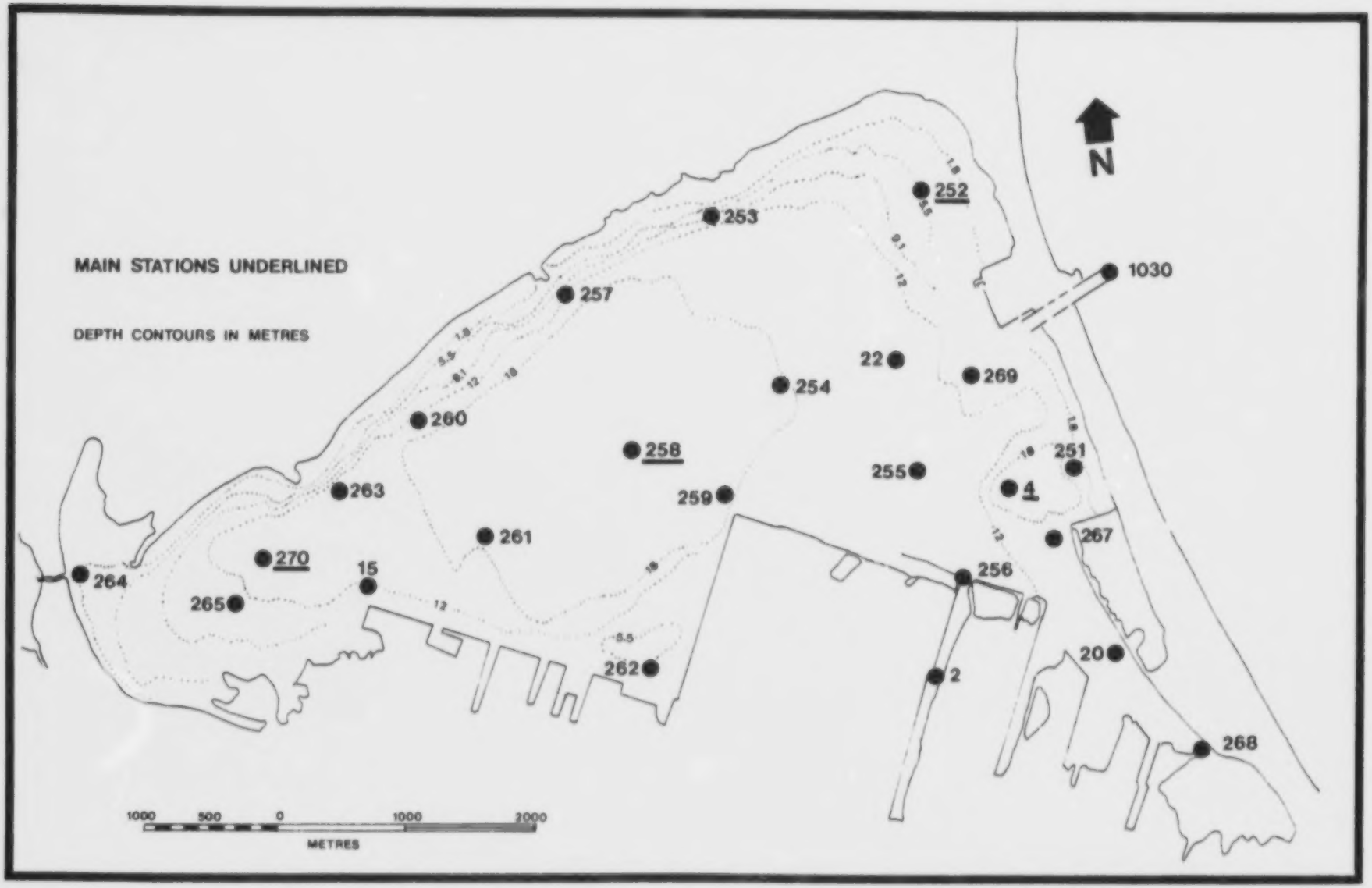

FIGURE 3.1 : 1977 HAMILTON HARBOUR SEDIMENT SAMPLING LOCATIONS

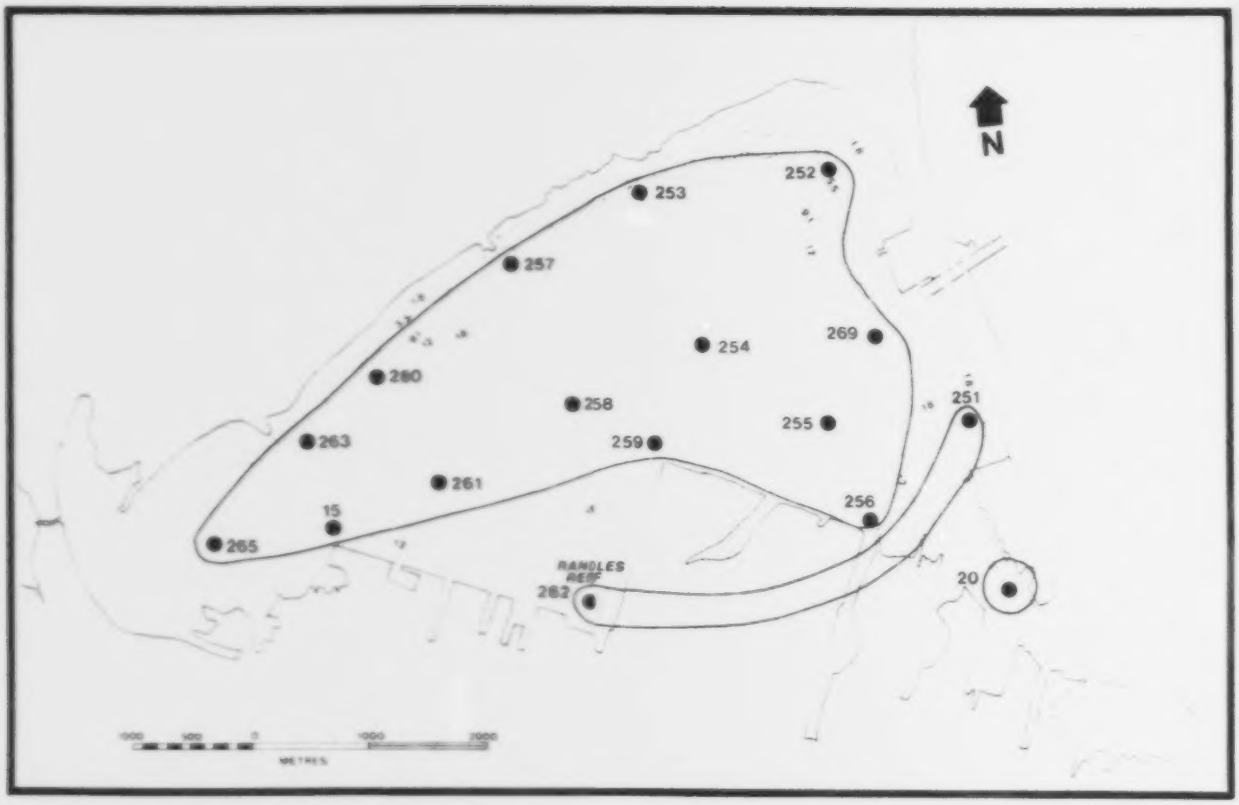

FIGURE 3.2 : RESULTS OF CLUSTER ANALYSIS OF SURFACE WATER SAMPLES TAKEN AT 17 STATIONS IN 1972

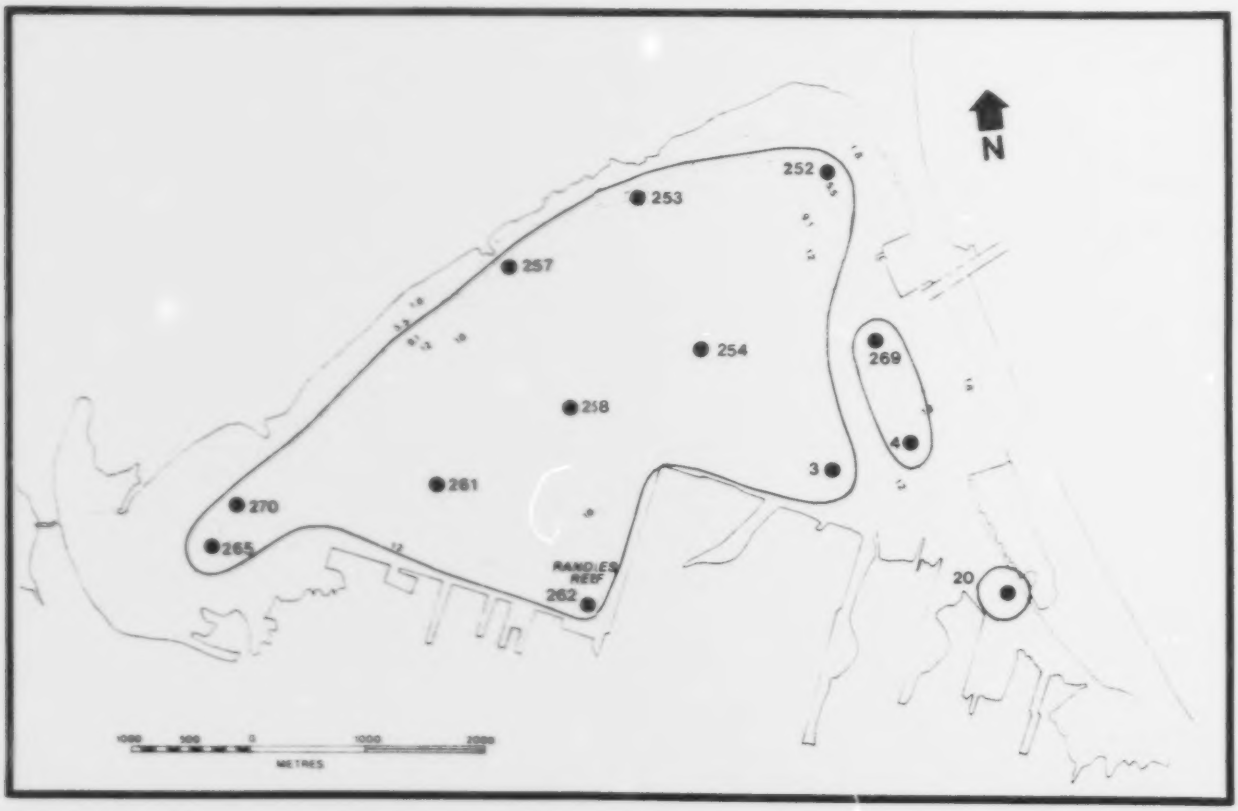

FIGURE 3.3 : RESULTS OF CLUSTER ANALYSIS AT SURFACE WATER SAMPLES TAKEN AT 13 STATIONS IN 1980

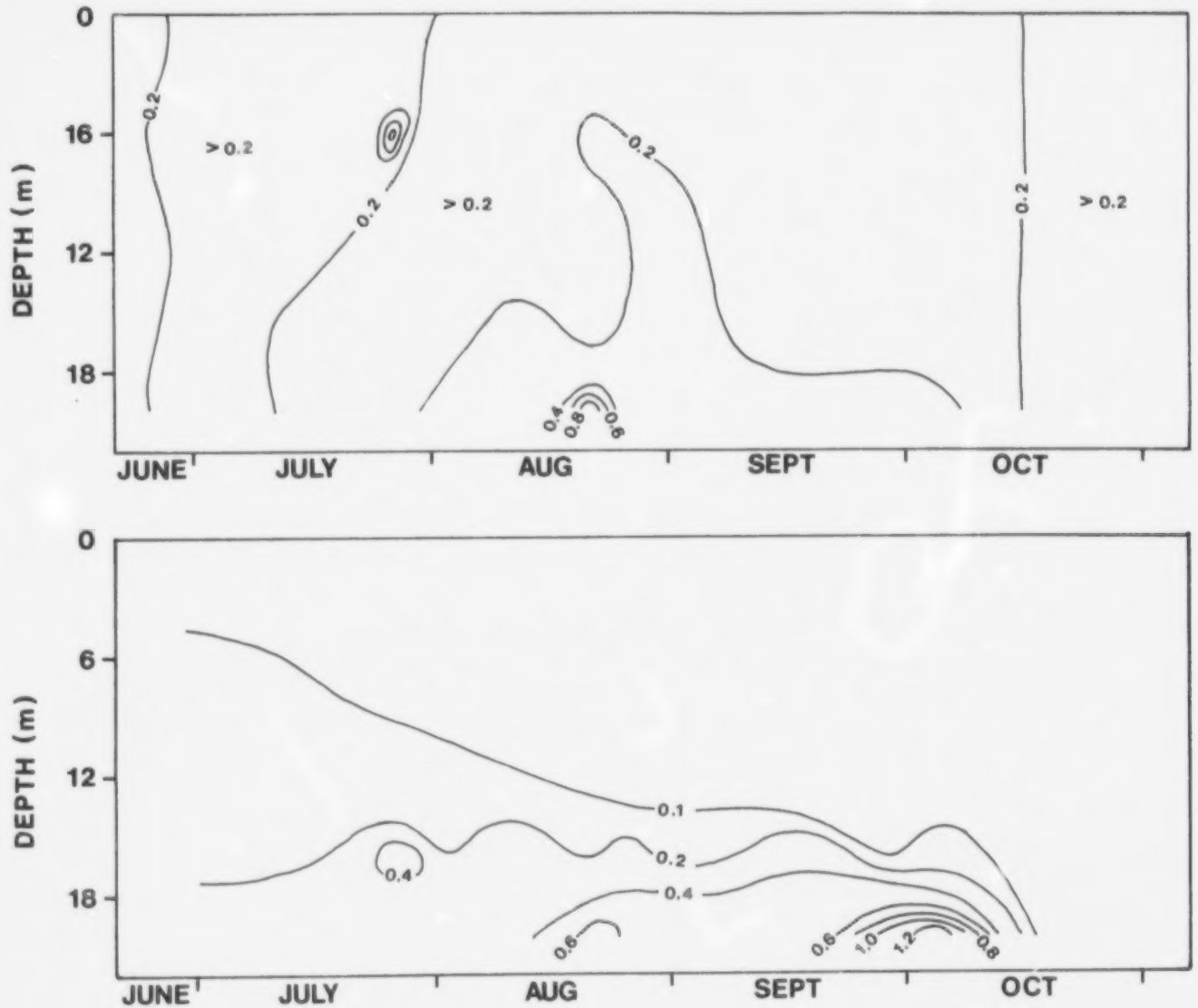

FIGURE 3.4 : ISOPLETHS OF IRON AND MANGANESE (mg/L) AT STATION 258, 1979

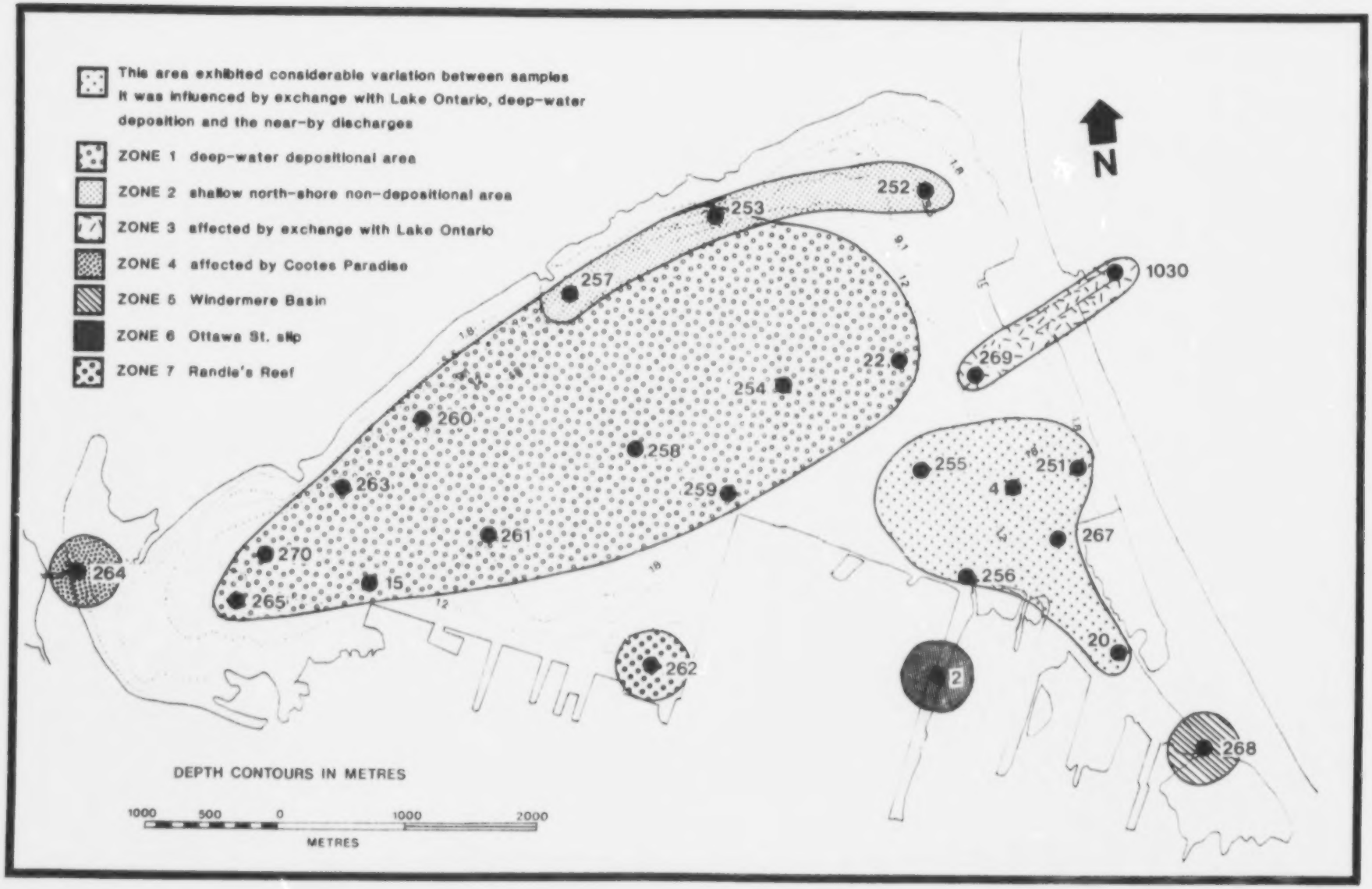

FIGURE 3.5 : HAMILTON HARBOUR SEDIMENT ZONATION.
COMPOSITE OF ZONES OBTAINED IN ANALYSIS OF 1975 TO 1980 DATA

4.0 PHYTOPLANKTON

Phytoplankton are unicellular microscopic algae which occur naturally in water bodies and which may represent the primary or sole source of plant material in a particular aquatic ecosystem. Phytoplankton grow and multiply through photosynthetic processes that manufacture organic substances from inorganic ones (e.g. carbon, nitrogen, phosphorus) using chlorophyll, a light harvesting molecule. Phytoplankton form the base of the aquatic ecosystem's biomass pyramid, and provide food for other organisms in the food chain.

The amount of algal material (biomass) which can be estimated by the amount of chlorophyll present, and the species composition or community structure of the phytoplankton, are governed by a number of abiotic and biotic factors. Some of the abiotic factors include light, temperature and nutrients such as phosphorus and nitrogen. Some examples of biotic factors are grazing, predation and competition.

As nutrient levels are increased in the water body, for example, from sewage treatment plant effluents, algal biomass will increase until limited or checked by some other factor such as light intensity. In addition, nutrient enrichment will likely cause changes in the phytoplankton community composition.

Large increases in algal biomass are undesirable since they can result in reduced water clarity, increased colour (both from the chlorophyll itself and from excreted organics), reduced dissolved oxygen concentrations (as a result of bacterial decomposition of plankton cells), and filter clogging at water intakes.

Community composition changes may also result in undesirable species changes in other trophic levels (eg., zooplankton, zoobenthos, fish). In addition, certain species may cause taste and odour problems in drinking water or may render the area aesthetically unsuitable for swimming. It is therefore important to know the types of phyto-plankton present as well as the volume of biomass. Once the factors controlling community structure and biomass are known, it may be possible to take some action to correct undesirable aquatic conditions.

The phytoplankton ecology of Hamilton Harbour was therefore examined by a number of investigators over the period 1976-1983 to ascertain relationships between phytoplankton growth and water quality, and to evaluate the influence of the plankton on the severe oxygen depletion problem in the Harbour.

4.1 Carbon

Integral photosynthesis in Hamilton Harbour was lower than one would predict based on chlorophyll and nutrient concentrations and varied irregularly throughout the ice-free periods each year, ranging from 25 to 220 mg carbon/m^2/h (Harris *et al.* 1980, II; Vollenweider *et al.* 1974). Since the area of the harbour is approximately 2.2×10^7 m^2, the amount of organic carbon fixed daily probably ranges from 3.3 to 58 metric tonnes using the conversions proposed by Glooschenko *et al.*.

Although organic carbon loadings to the harbour from industry and the municipalities was not measured directly, they can be estimated from the values for chemical oxygen demand (COD). Using this conversion, the average daily loading of organic carbon to the harbour was approximately 35 metric tonnes per day; however, this method tends to overestimate the actual load of the organic carbon which is quickly biodegradable.

The standing stock (total amount) of organic carbon present in the water column in 1979 ranged from a low of 730 metric tonnes (± 25%) during the winter period to a high of 1300 metric tonnes (± 22%) during the summer period. Therefore, the average daily loadings to the harbour represent from 3 to 5% of the standing stock while the daily photosynthetically produced organic carbon represents from 0.5 to 5% of the standing stock. It is however, important to note that the organic carbon produced by phytoplankton is up to 1.5 times greater than the daily carbon loadings from municipal and industrial sources. Since degradation of organic carbon by bacteria is an oxygen consuming process, any strategy to reduce oxygen demand in the harbour should include a plan to limit primary production as well as effluent loadings of organic carbon.

4.2 Nitrogen

Nitrogen is a major nutritional requirement for phytoplankton growth. A variety of organic and inorganic forms (e.g., ammonia and nitrate) are present in the harbour in excessive concentrations; however, it is the inorganic forms which are used as a nutrient for growth by the algae.

"When both nitrate and ammonia are present together, ammonia is usually taken up to exhaustion before uptake of nitrate begins" (Healey 1973). Maximum phytoplankton cell densities (another biomass measure) coincide roughly with the minimum ammonia concentrations in the harbour. Thus, uptake by phytoplankton likely removes significant amounts of ammonia from the water column. This further explains why a concomitant increase in the nitrate concentration is not observed, as would be expected if nitrification were the sole cause of ammonia removal. This also explains why the reduction in ammonia concentrations and the oxygen depletion rates, observed in the water column, are not more closely synchronized.

Ammonia and nitrate concentrations are always high enough in the harbour that nitrogen does not limit algal growth. Furthermore, the ratios of particulate nitrogen to particulate phosphorus are usually in the range of 14-18:1, which is very near the Redfield Ratio (Redfield 1958). This is the mass for mass ratio which should be observed for healthy, mixed species populations, growing maximally, without nutrient limitations.

These results imply that the phytoplankton are not nutrient (nitrogen or phosphorus) limited. This conclusion is further supported by a series of nutrient enrichment experiments conducted at McMaster University (Piccinin 1976). The results of those studies, combined with the measurements of nitrogen concentration in the harbour, suggest that nitrogen concentrations could be reduced by 60-85% of their 1979 values without affecting primary production.

Inorganic nitrogen, and inorganic carbon are taken up by phytoplankton in a ratio of 5-7 to 1 (Rhee 1980), implying that organic nitrogen is produced by the algae at the rate of 4.6 to 41 metric tonnes per day in the harbour. The external load from municipal and industrial sources in 1979 was in the range of 18 to 25 metric tonnes per day; therefore, it can be seen that internally produced nitrogen exceeds the externally loaded nitrogen by a factor of up to 1.6 during the period of maximum algal growth (usually summer). While this large internal pool of nitrogen is not all available for decomposition it does represent a significant, potential source of oxygen demand which is manifested as the algae die off. Therefore, any management strategy developed to improve the dissolved oxygen conditions in the harbour through the reduction of oxygen demanding nitrogen loads must also consider the potential significance of the internally produced demand.

4.3 Phosphorus

Phosphorus, the nutrient which is considered to be the major factor controlling the biomass of north temperate lakes (Dillon et al. 1978; Schindler 1977, 1974) and therefore their trophic status, is present in excessive levels in Hamilton Harbour. The high concentrations of phosphorus observed are a direct result of the municipal and industrial discharges and the hydraulic residence time (Table 4.1).

The fate of phosphorus in the harbour can be examined using a mass balance model which assumes steady state conditions. The model suggests that the majority (67%) of the annual loading is sedimented out in the harbour (Table 4.2). This implies that the sediments are a major sink for phosphorus and that both present and future water quality may be greatly affected if the phosphorus is liberated from the sediments and re-introduced to the water column. Biomass levels could therefore remain high despite any loading reductions to the harbour which may be instituted.

The present and future effects of phosphorus in the sediments are not readily quantifiable due to our present lack of knowledge of sediment transport to Lake Ontario from the harbour and phosphorus release under

anoxic conditions within the Harbour. While chemically-bound phosphorus is known to be released from sediments under anoxic conditions (Holdren and Armstrong 1980), this has not been adequately documented or quantified in the harbour.

Nutrient loadings and algal biomass (as estimated by chlorophyll concentrations) can be related through the use of empirical models. Some models can be used to predict the annual average chlorophyll concentration (Janus and Vollenweider 1981), while others predict the average summer chlorophyll concentration (Chapra and Dobson 1979, Dillon and Rigler 1974). The latter may be of greater interest since it is the summer maximum concentrations which are more likely to generate public complaints or enquiries, and which may be responsible for excessive oxygen demands in the hypolimnion due to bacterial degradation of the algal material.

The Janus-Vollenweider model prediction of the average annual chlorophyll concentration closely approximates the observed harbour average (Table 4.3). The model prediction is highly sensitive to the hydraulic residence time of the harbour implying that the observed shortened residence time reduces the potential biomass level by 33% compared with a closed system (i.e. having no outflow).

The Chapra-Dobson model (1979) and the Dillon-Rigler model (1974) both attempt to predict average summer chlorophyll levels. While both models predict values well above the observed concentrations, the Dillion-Rigler model more closely approximates the maximum summer values than the average value (Table 4.3).

The models were used to examine the effects of both increasing and decreasing phosphorus loads on algal biomass in the harbour (Table 4.4). These scenarios examine chiefly the effects of changes at the Hamilton STP, since its contribution was approximately 72% of the total 1979 load and about 44% of the total 1982 load of phosphorus. The results show that the response of the algal biomass to an increase in hydraulic load is dramatic, and only if the effluent concentration is reduced to 0.1 mg/L is this effect nullified.

The modelling and McMaster bioassay results, combined with observations of highly variable chlorophyll levels over short periods of time during the summer, suggest that algal biomass is strongly influenced by factors other than phosphorus concentrations.

It is not presently possible to reliably quantify the relationship between oxygen depletion and the total phosphorus load; however, reductions in total phosphorus loads to levels which limit and therefore reduce algal biomass would probably also result in lowered oxygen demands.

4.4 Primary Production and Physical Factors

In addition to water temperature and lake-harbour exchange (i.e. the movement of harbour waters to the lake and vice versa), two major physical factors affecting primary production are vertical mixing and light penetration.

Sunlight is the source of energy used in photosynthesis and is therefore a fundamental requirement for primary production. The depth to which the energy penetrates the water column defines the volume of water in which primary production may occur; this is called the euphotic zone and is delimited by the depth to which 1% of the surface irradiance energy penetrates. Below the euphotic zone, photosynthesis cannot proceed because of energy limitation (Talling 1957 a and b; 1971).

The depth to which light penetrates in a column of water is dictated by the amount of scattering it undergoes as a result of suspended particulate material and by the amount of absorption from dissolved and particulate materials. In Hamilton Harbour, the euphotic zone depth is normally 2 to 4 metres from the surface during the ice-free period of the year (Harris et al.1980, I). The shallowness of this zone is due to light scattering in the highly turbid waters and to absorption, due in part to the phytoplankton themselves, but mostly due to dissolved organic compounds in the water.

During the unstratified periods of spring and autumn, surface and bottom water temperatures in the harbour are nearly identical (isothermal) and complete vertical mixing takes place. During the summer, the temperature difference between well-mixed surface waters and quiescent bottom water creates a density barrier which prevents complete vertical mixing. The layer of greatest temperature/density change is known as the thermocline. In Hamilton Harbour, during the summer, the thermocline is located about 7 metres from the surface; however, due to energy and mass inputs from Lake Ontario as well as wind effects, the thermocline depth, and therefore the mixing depth, is highly variable.

The rapid and large changes in mixing depth as well as the shallow euphotic zone depth are major factors limiting algal biomass. When prolonged periods of stability occur, primary production is such that the phytoplankton become self-shading, that is the biomass absorbs the light energy to a degree which limits further production. On some occasions, the theoretical maximum algal biomass can be realized in the harbour.

If dissolved organic compounds and non-living suspended particulates were eliminated in the harbour through source control, but nutrients were not similarly controlled, minimum summer biomass levels theoretically could increase by as much as 65%. However, maximum biomass levels should not increase above those already observed, since ultimately the populations would become self-shading and limit further growth.

4.5 Primary Production and Toxic Effects

Toxicity testing at McMaster University (Piccinin 1976) on the effects of zinc and copper indicated that harbour phytoplankton populations are adapted to elevated levels of these metals. Other researchers have found that low concentration mixtures of metals did have large, inhibitory effects on harbour phytoplankton (Wong *et al.* 1978). The complete effect on the harbour biomass cannot be projected with any accuracy due to fluctuations in the concentrations of the various metals in the harbour and the changing phytoplankton community composition.

Although the effects of the dissolved organics present in the harbour have not been examined, the overall impact of toxicity on primary production is probably secondary when compared with physical factors.

4.6 Community Composition

The phytoplankton species of Hamilton Harbour are typical of a highly eutrophic lake (Piccinin 1976; Taylor *et al.* 1981). Analysis has shown a clear seasonal trend in the species assemblages which was similar from year to year. In addition, the phytoplankton biomass and community structure appear to be controlled primarily by physical factors (Harris *et al.* 1980, II).

Of the many algal species present in the harbour, a discussion of two groups, the Cryptophyta and the Cyanophyta, will serve to illustrate the present environmental problem and the complexity of the solutions.

The Cryptophyta or cryptomonads are a ubiquitous group of algae. They are found throughout the Great Lakes as well as in small ponds and sewage lagoons. This group, represented in the harbour by *Cryptomonas* spp. and *Rhodomonas minuta*, are thought to be facultative heterotrophs - that is they are capable of using organic as well as inorganic carbon sources for growth. In addition to this group, many of the centric diatoms and some of the blue-greens are thought to be facultative heterotrophs (Droop 1974). Their presence in significant numbers may explain the close correspondence of the observed and predicted relationship between average annual chlorophyll and total phosphorus despite the extremely variable physical environment. The limitations on production imposed by the absence of a predictable and adequate light supply have been circumvented or diminished by the abundant supply of organic carbon compounds which can be utilized as an energy source for growth. This suggests that organic carbon inputs should be abated, not only to decrease related oxygen demands, but also as a means of reducing algal biomass.

The Cyanophyta, or blue-green algae, are present in the harbour in very small numbers, with only two recurring species, Oscillatoria sp. and Anabaena sp. The elevated nutrient levels, high summer temperatures and high concentrations of organics in the harbour provide ideal conditions for the development of large blooms of blue-greens, particularly those species of Microcystis and Aphanizomenon which are associated with taste and odour problems (Whitton 1973, Reynolds and Walsby 1975, Reynolds 1972).

Growth of these organisms in significant numbers in Hamilton Harbour is prevented by the rapid and large changes in mixing depth combined with shallow light penetration. Under these conditions the competitive advantage of buoyancy compensating mechanisms is lost and the major limiting resource becomes photosynthetic energy. This suggests that nitrogen levels could be reduced drastically (to the point of limitation for other species of phytoplankton) without significantly increasing the densities of nitrogen fixing blue-green algae (Reynolds and Walsby 1975, Smith 1983).

4.7 Summary and Conclusions

1) Phytoplankton biomass in Hamilton Harbour does not appear to be limited by nitrogen or phosphorus at present; instead it is controlled by a highly variable mixing depth combined with shallow light penetration.

2) Algal primary production is responsible for the fixation of 6.5 to 58 metric tonnes of organic carbon per day which is 0.2 to 1.7 times the estimated external load in 1979. In addition, 4.6 to 41 metric tonnes per day of organic nitrogen is similarly fixed - 0.2 to 1.6 times the estimated external load for 1979. Both organic carbon and nitrogen (in addition to other reduced nitrogen forms such as ammonia) are responsible for much of the oxygen demand in the harbour, and algal biomass is a major contributor to these reservoirs. Any attempt to rectify the dissolved oxygen problem in the harbour must incorporate provisions to limit primary production.

3) The Hamilton sewage treatment plant may be a major factor in future algal biomass control through phosphorus limitation in the harbour since it will remain the largest source of phosphorus to the harbour.

4) The euphotic zone is from 2 to 4 metres deep in the harbour and is governed by the high levels of suspended solids and dissolved organics present. A reduction in the load of these materials, in the absence of significant reduction to phosphorus loads, could result in an increase in the maximum summer phytoplankton biomass level. Therefore, any abatement of present loads should be carefully co-ordinated to avoid a worsening of certain aspects of water quality.

5) Although the waters of Hamilton Harbour contain metals in sufficient concentrations to have an inhibitory effect on algal growth, many of the species appear to be adapted to these conditions and are therefore unaffected. The total effect of metals and organic substances on the phytoplankton has not been quantified, but it is estimated to be minor compared to physical effects.

6) The phytoplankton species observed in the harbour are typical of a highly enriched body of water. Although blue-green algae are present, their densities are low, and nuisance blooms are prevented by irregular and large changes in the mixing depth.

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TABLE 4.1

COMPARISON OF OBSERVED AND PREDICTED AVERAGE TOTAL PHOSPHORUS CONCENTRATIONS FOR HAMILTON HARBOUR

Average loading conc.[a]	190 mg/m^3
Average loading corrected for residence time[b]	127
Predicted average harbour conc.[c]	80
Observed average harbour conc.	102

a Average daily load/average flow

b Avg. loading conc./1 + T_w where T_w is the hydraulic residence time (= 0.25y for the harbour)

c Based on graphs in L.L. Janus and R. A. Vollenweider, ed. (1981). "The Canadian contribution to the OECD co-operative programme on eutrophication."

TABLE 4.2

TOTAL ANNUAL PHOSPHORUS BUDGET (1979)[a]
FOR HAMILTON HARBOUR

	10^4 kg	% of input
Input[b]	36.5	100
Output[c]	9.7	33
Sedimented[d]	24.6	67

a Assuming steady-state conditions and an annual average concentration of total phosphorus of 80 mg/m^3

b Daily input (refer to Loadings Section) x 365

c Average annual concentration x yearly flow to lake (=3.3 x 10^6 m^3/d x 365)

d Calculated as residual.

TABLE 4.3

COMPARISON OF PREDICTED AND OBSERVED ANNUAL AND SUMMER MEAN CHLOROPHYLL CONCENTRATIONS FOR 1979

Observed annual average	18 mg/m^3
Janus-Vollenweider prediction	19
Observed mean summer	24 mg/m^3
Chapra-Dobson prediction	31
Dillon-Rigler prediction	97
Observed summer maximum	74

TABLE 4.4

EFFECTS OF PHOSPHORUS LOADING SCENARIOS ON ALGAL BIOMASS

Phosphorus loading scenarios[1]	Average TP loading con[2] (mg/m^3)	Predicted average annual TP con.[3] (mg/m^3)	Predicted Average annual Chl conc.[4] (mg/m^3)	Predicted average summer Chl. Conc.[5] (mg/m^3)	Predicted max. summer Chl. conc.[6] (mg/m^3)
a[7] 250 x $10^3 m^3/d$ @ 1.0 g/m^3 (60 mgd)	109 (73)	60	15	18	28
b 250 x 10^3 @ 0.5	86 (57)	48	10	13	20
c 250 x 10^3 @ 0.1	66 (44)	34	8	8	12
d 400 x 10^3 @ 1.0 (90 mgd)	114 (76)	69	17	24	34
e 400 x 10^3 @ 0.5	92 (61)	51	12	17	22
f 400 x 10^3 @ 0.1	64 (43)	34	8	8	12
g[8] 550 x 10^3 @ 1.0 (120 mgd)	149 (99)	80	19	29	42
h[8] 550 x 10^3 @ 0.5	102 (68)	55	13	18	24
i[8] 550 x 10^3 @ 0.1	65 (43)	34	8	8	12
j[9] All direct discharges removed	43 (29)	27	6	7	9

1 Changes in all cases except j to Hamilton STP only; flows and conc. of TP in final effluent indicated.
2 All sources including Lake Ontario. Number in brackets represents concentration corrected for residence time.
3 Janus-Vollenweider model prediction based on 0.25 residence time which includes lake-harbour exchange.
4 Janus - Vollenweider model.
5 Chapra-Dobson model.
6 Dillon-Rigler model, assuming annual mean TP = spring mean TP (will be an underestimate of actual value).
7 1982 hydraulic and effluent conditions from HSTP
8 Planned hydraulic expansions to HSTP
9 All direct discharges include HSTP, BSTP, Stelco, Dofasco

5.0 BACTERIAL POPULATIONS IN HAMILTON HARBOUR

Examinations of the bacteria present in a body of water and their significance have mainly been confined to human health considerations. The driving force behind this approach has been the need to assure the safety of the water for swimming, bathing and its use as a potable water supply. Traditionally, tests for the detection and enumeration of indicator organisms, rather than of pathogens (the disease causing organisms), have been used. The coliform group of bacteria has been the principal indicator of the suitability of the water for human use. Experience has established the significance of coliform group densities, providing criteria of the potential degree of health risk (MOE 1984).

In spite of our interest in eutrophication, oxygen demand and the biogeochemical cycling of nutrients, the significance of microbial populations and their activities are often ignored in water quality studies. Although there is little specific information on the Great Lakes, it is apparent that bacteria significantly influence the production ecology of other freshwater and marine systems (Heukelekian and Dondero 1964, Collins 1963, Kuznetsov 1968). This is particularly true in Hamilton Harbour where the volumetric planktonic biomass of the bacteria is roughly equivalent to that of the phytoplankton (MOE 1977).

Since the water column oxygen demand represents 80% of the total oxygen demand in the harbour, an investigation of the microbial processes and the factors impinging on these process was imperative.

5.1 Public Health

In order to ascertain the degree of impairment associated with fecal contamination, fecal coliform densities were measured biweekly at stations throughout the harbour, May through October, from 1975 through 1980. The annual geometric mean densities for the harbour declined each year from a high of 68 in 1974 to a low of 13 in 1979. In addition, the number of individual samples which exceeded the Ministry's Objective of 100 counts per 100 mL (MOE 1984) fell

dramatically to a total of 12 in 1979 from 45 in 1976. The data showed that the highest coliform densities are found in the area immediately adjacent to Windermere Basin. Densities are also elevated in the western end of the harbour adjacent to Cootes Paradise.

The continued decline in fecal coliform densities since 1975 indicates a definite improvement in this aspect of water quality.

5.2 Carbon

The heterotrophic bacteria, which includes the ammonifying bacteria, are a heterogeneous group of organisms requiring organic carbon for growth and oxygen for metabolic processes. The significance of the ammonifying bacteria and their activities is discussed in the section on nitrogen. Since the density of organisms in this group is estimated using a non-specific test, it is not surprising that the numbers of heterotrophic bacteria exceed those for all other groups measured.

Densities are greatest in the eastern end of the harbour and next greatest in the western end, being highly correlated with the distribution of fecal coliforms. Levels are elevated in the surface waters where temperature, dissolved oxygen, algal biomass and dissolved organic carbon concentrations are highest. The numbers of heterotrophic bacteria are highly variable from year to year; however, due to the inexact nature of the measurement no significance can be attached to these differences. Heterotroph numbers are greatest in the spring and autumn, followed by the winter and finally the summer, suggesting that densities are not strictly controlled by temperature. In addition, the presence of high concentrations of dissolved organic carbon throughout the year would suggest that they are not substrate limited. Since pH changes little spatially and temporally in the harbour, the major factor limiting growth and metabolic activity during the summer would appear to be low dissolved oxygen concentrations. This conclusion was supported by the results of laboratory experiments.

In an attempt to measure the oxygen demand associated with organic carbon decomposition, laboratory investigations of oxygen consumption rates were conducted in 1979 and 1980. Since all particulate material greater than 10 microns was screened out to eliminate oxygen consumption through algal respiration, much of the phytoplankton component, which may have been available for decomposition, was not included. As a result, all of the oxygen consumed due to organic carbon decomposition was not measured; however, since most of the organic carbon present in the harbour is dissolved, the experimental bias may not be significant. The inclusion of the oxygen demand associated with ammonification (refer to nitrogen section), would produce an overestimate of the importance of carbonaceous oxygen demand particularly during the spring and summer months and may significantly affect these conclusions.

The measured oxygen consumption rates varied from near zero to over 2 mg/L per day. The highest demand rates occur during the late autumn and early winter, but significant demands persist throughout the year. The results showed that the oxygen demand due to organic carbon decomposition varies from 10-60% of the total water column oxygen demand. Therefore, decomposition of organic carbon accounts for a highly significant portion of the dissolved oxygen consumed during certain times of the year.

Other studies have shown that the oxidation of methane gas, which is produced in the harbour sediments, accounts for a maximum of 6% of the total water column oxygen demand (Snodgrass 1977).

5.3 Sulphur

Sulphur in the environment can exist in a variety of oxidation states depending on the Eh (a measure of the oxidizing or reducing potential) and pH of the environment. Many chemical reactions of sulphur compounds are relatively slow; microorganisms play an important role in the sulphur cycle as catalysts of these reactions.

Bacteria responsible for the oxidation of a variety of reduced sulphur compounds were found in Hamilton Harbour at very high densities, second only to the heterotrophs. Although a number of species may be important in this portion of the sulphur cycle, it was only possible to test for a few species of the genus Thiobacillus at the Ministry of the Environment main laboratory.

Sulphur reducing bacteria were found to be present in significant, but fewer numbers than the sulphur oxidizers. These reducers represented by two or three genera only, are responsible for the reduction of oxidized forms of sulphur, mainly sulphur dioxide under oxygen free or anaerobic conditions. Since there is no known chemical mechanism for the reduction of sulphate by organic matter at ambient temperatures and pressures, microorganisms are completely responsible for this process (Goldhaber and Kaplan 1974).

Annual, harbour-wide, geometric mean densities of sulphur oxidizing bacteria have changed dramatically, but irregularly, since 1975. This suggests that the significance of these bacteria and the sulphur oxidizing processes to oxygen depletion may be quite variable from year to year. In general, densities decrease with depth and from the eastern to the western end of the harbour. This suggests a strong link between bacterial numbers and the point source inputs. The major sources of sulphur compounds to the harbour are the steel industries, followed by the Hamilton Sewage Treatment Plant.

The species of Thiobacillus measured are capable of oxidizing elemental sulphur, sulphide or thiosulphate; however, other species, which are also likely to be present, are capable of oxidizing metal-sulphur compounds, organic sulphur compounds and polythionates (Kasmans 1967, Vishniac and Santer 1957, Kuznetsov 1970, MOE 1981).

A laboratory experiment, which investigated the significance of various oxygen demanding microbial activities in the water column, showed that the oxygen demand due to sulphur oxidation varied from near zero to 2.0 mg/L per day. Oxygen demand was greatest during the spring and autumn periods, and accounted for 20 to 70% of the total water column oxygen demand.

It is evident that oxygen depletion due to sulphur oxidation by bacteria is significant and any abatement programs directed at alleviating the dissolved oxygen problem must include a strategy for controlling sources of sulphur.

The densities of sulphur reducing bacteria showed little change with depth or season. Population numbers were highest in the southeastern corner of the harbour, but showed little change in annual, harbour-wide, geometric means from 1975 through 1979.

Although these organisms do not consume oxygen in their metabolic and biochemical transformation process, their activities do contribute a supply of reduced sulphur compounds which in turn can be utilized by other oxygen consuming bacteria.

5.4 Nitrogen

A simplified nitrogen cycle, with sources and sinks for Hamilton, Harbour is presented in Figure 5-1. The figure presents a simplified cycle in the sense that some intermediate steps are omitted and some chemical forms (such as ammonia and urea) are not explicitly included.

Studies of the nitrogen cycle of Hamilton Harbour examined the nitrification portion of the cycle. Nitrification is a two step bacterially mediated process: the conversion of ammonia to nitrite by species of Nitrosomonas, and the conversion of nitrite to nitrate by species of Nitrobacter. Ammonification, the microbially, mediated process of converting organic nitrogen to ammonia, and the bacteria responsible for this process, were not examined separately. The bacterial numbers are included in the general enumeration of the heterotrophs. In addition, the oxygen demand associated with ammonification is inseparable from that of organic carbon decomposition and therefore is not uniquely quantified.

Population densities of the nitrifiers show extremely high fluctuations not just seasonally, but also on a weekly basis. The variability seen is larger than that of the other bacterial groups measured. This is due in part to the large number of species measured in the enumeration of heterotroph and sulphur oxidizes and the greater sensitivity of the nitrifiers to changes in environmental factors such as dissolved oxygen, pH, temperature, and toxics (Aleem 1970, Sharma and Allert 1977, Stenstrom and Poduska 1980, Quinlan 1980). The presence of significant concentrations of ammonia in the harbour throughout the year indicates that these bacteria are not substrate limited. Populations are highest in the summer (after the major declines in ammonia are observed) and spatially distant from the point sources located in the eastern end. This further attests to the significance of the phytoplankton (and primary production) as both a sink for ammonia and a source of organic nitrogen.

Although ammonification was not measured directly, an estimate of this process can be achieved. If the week by week changes in harbour ammonia concentration are examined in relation to the measured inputs of ammonia from external sources and its calculated transport to Lake Ontario, an estimate of the internally produced ammonia can be made. Calculations based on these relationships indicate that the ammonia produced in the harbour, as a result of ammonification of internally produced organic nitrogen as well as externally loaded organic nitrogen, may exceed 90% of the point source loadings of ammonia during peak accumulation periods in the water column. This implies that organic nitrogen produced within the harbour (mainly by the phytoplankton) represents a significant source of oxygen demand through ammonification and ultimately nitrification.

Results of laboratory tests parallelled the dramatic variations in oxygen demand seen in the field. Measured demand rates ranged from zero to 1.45 mg/L per day. Rates are greater in late June and again in late August. The seasonal contribution of nitrification to the total water column oxygen demand ranges from 10% to 45%.

5.5 Summary and Conclusions

1. Fecal coliform levels have declined steadily since 1975 to a point where the criterion for swimming and bathing (100 organisms per 100 ml) is seldom exceeded.

2. Population densities of nutrient cycle bacteria are extremely high in the harbour and, except for the nitrifying bacteria, are greatest near the point sources.

3. Nitrification, sulphur oxidation and organic carbon decomposition all contribute significantly, throughout the year, to the low dissolved oxygen concentration in the harbour.

   While the actual demand rates are quite variable, each process can be seen to dominate water column oxygen demand at different times of the year. Laboratory experiments support the following generalizations of the processes responsible for oxygen demand in the water column at various times of the year:

   late winter through early spring..... sulphur oxidation
   late spring through early summer ..... nitrification
   late summer through early autumn ..... nitrification and carbon demand
   late autumn through early winter ..... carbon demand.

4. Nutrient cycle bacterial populations are not substrate limited. Population growth and metabolic processes in the harbour are controlled by physical/chemical factors such as temperature and dissolved oxygen concentrations. These factors affect each species and their processes differentially which results in complex relationships between oxygen consumption and the various nutrient forms.

5. Remedial programs aimed at correcting the dissolved oxygen problem in Hamilton Harbour must address the internally produced organic material (primary production) which is likely responsible for significant oxygen depletion through a variety of microbial activities.

   In addition, point source abatement measures must address a variety of chemical inputs (i.e. organic nitrogen as well as ammonia) rather than focusing on any single chemical in order to improve the dissolved oxygen levels in the harbour.

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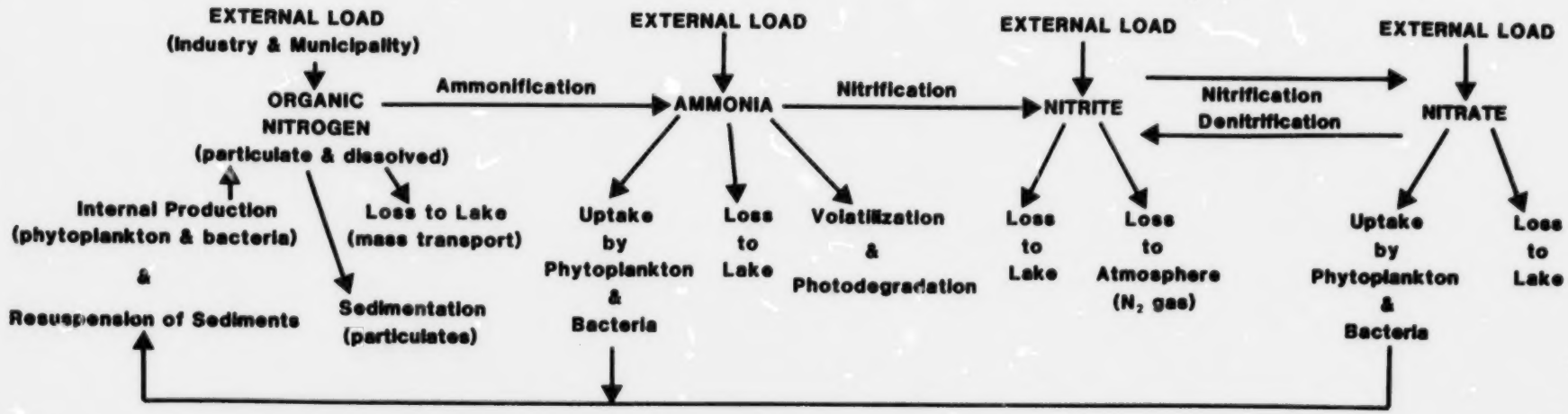

FIGURE 5.1 : SIMPLIFIED NITROGEN CYCLE (WITH SOURCES AND SINKS) FOR HAMILTON HARBOUR

6.0 THE DISSOLVED OXYGEN REGIME IN THE HARBOUR

6.1 The Oxygen Regime in the Harbour

The average concentrations of dissolved oxygen in the epilimnion and hypolimnion for the period 1976 to 1980 are shown on Fig. 6.1a and 6.1b. After a rapid decline of the oxygen in May and June, the hypolimnion concentration remains close to zero until mid-September. Below-saturation concentrations in the whole water column can persist even as late as mid-December. The oxygen concentration varies considerably at any particular date from station to station and year to year. Figures 6.2a and 6.2b exemplify the conditions in 1978.

Oxygen in the water is consumed by biological processes that take place both in the water column and at the water/sediment interface (section 5.0). The main oxygen demand is due to the bacterial oxidation of reduced carbon, nitrogen and sulphur compounds, which are present in the effluents from industry and the municipalities (section 2.0) or produced in situ by phytoplankton growth. Oxygen is added from photosynthesis and reaeration from the atmosphere to the epilimnion; also from the inflow of oxygenated water through the canal and from tributaries. In the summer, flow from the lake is to the hypolimnion, preventing continuous anoxia in July and August. Since the water column is thermally unstable during the summer, vertical mixing is pronounced and oxygenated water is mixed into the hypolimnion while oxygen depleted water is mixed into the epilimnion (see section 1).

6.2 The Two-Layer Dissolved Oxygen Model

6.2.1 General features and limitations of the model

A model, which consists of separate but interlinked models for dissolved oxygen and carbonaceous and nitrogenous biological oxygen demand, was developed to describe the oxygen regime in the harbour and to predict changes in the regime if inputs from industry and municipalities are changed. A detailed description of the model, its calibration and sensitivity analysis, is given by Poulton (1982), and is summarized here.

The main features are:

1. Physical:

   (a) The harbour is assumed to be horizontally well-mixed at all times. During spring and fall it is also vertically well mixed and is thus treated like a continuously-stirred tank reactor (CSTR) with vertical sides and a depth of 13 m (mean harbour depth). During the summer (thermal stratification), the epilimnion and hypolimnion are treated as separate CSTR's with the thermocline at 7 m depth.

   (b) The lake-harbour exchange is represented by a two-layer system despite the complexities in the observed flows (section 1.0). During stratification, all lake water is assumed to enter the hypolimnion.

   (c) The magnitude of reaeration is not known with any precision. Several empirical expressions are found in the literature for the reaeration transfer coefficient, which can produce differences in the simulated mid-summer surface oxygen of up to several mg/L. Convective transport, induced by exchange with Lake Ontario, is simulated as moving deoxygenated hypolimnion water to the epilimnion. Diffusion between the layers, as well as settling of particulate oxygen-demanding material from the epilimnion to hypolimnion, and from the hypolimnion to the sediments, were also included in the model formulation.

2. Biological and chemical:

   (a) The major sinks of oxygen to the harbour include sediment oxygen demand (SOD), plus the water column demands, which include carbonaceous BOD (CBOD), as well as reduced nitrogen (NBOD) and sulphur (SBOD) demands. Not all known processes which add or subtract BOD or NBOD are included because the magnitudes or rates of many of them are unknown. Internal

production of BOD is assumed to be equal to the rate of oxygen production by net photosynthesis. Other internal sources such as the production of ammonia from particulate nitrogen (for example phytoplankton), and sinks such as the uptake of ammonia by phytoplankton or its escape to the atmosphere, are included in the loading of ammonia from external sources and their removal by nitrification and sinking of both BOD and NBOD to the sediments. It is further assumed that the rate constants obtained from calibration do not change when loadings are reduced. Since reduced sulphur loadings are not available, modified demand rates based on laboratory measurements of oxygen depletion due to reduced sulphur are used.

(b) The empirically measured sediment demand rates, which are functions of both the dissolved oxygen concentration and of temperature, may not adequately reflect seasonal or spatial variation. The rate at which the sediments will be oxidized following reduction of water column BOD and NBOD demands is unknown. This fact limits the usefulness of the model in predicting the long-term response to certain abatement scenarios.

6.2.2 Boundary Conditions for the Model

Measured 1979-80 values for all loadings and flows were used (section 1.0 and 2.0). Photosynthesis rates were averages of 1975-77 data as measured by Harris, Haffner and Piccinin (1980). Sediment oxygen demand rates were taken directly from measurements in the harbour by Snodgrass (1979), and by Polak and Haffner (1978). As a starting point, values of carbonaceous (CBOD), nitrogenous (NBOD) and sulphur (SBOD) demand rates from unpublished MOE laboratory investigations were used. The nitrogen and carbon demand rates were converted to rate constants, assuming first order reactions. Initial vertical exchange rates were calculated from observed oxygen-depth profiles and oxygen stock changes in the harbour; exchange measurements by Palmer (1981) on the upper 5 m of the water column were also used. Literature values were used for other terms such as reaeration (Banks and Herera 1977) and the settling of particulate carbon and nitrogen (Freedman, Canale and Pendergast 1980).

6.2.3 Model calibration and sensitivity analysis

The first step in the calibration was a test of the physical portions of the model by simulating chloride concentration, a conservative (nonreacting) substance. This allowed a test of the two-layer model formulation, and validation or adjustment of the hydraulic flow scheme (source inputs, lake-harbour exchange plus convective flow and vertical diffusion between the layers).

A vertical diffusion coefficient of 1.0 m^2/day = 0.12 cm^2/s was needed to simulate the observed epilimnetic and hypolimnetic chloride concentrations. This value was lower than expected based on observations of the vertical instability of the harbour, which would appear to dictate a higher value.

In order to simulate the observed summer decrease of chloride (both layers), it was necessary to increase the average monthly July-August exchange flow from the lake by 50% above those calculated by B. Kohli. The increase is within the range of exchange values discussed in Section 1. This exchange rate and vertical diffusion coefficient, used in the chloride model were also used in the oxygen model.

The measured rates of carbon, nitrogen and sulphur oxygen demand were adjusted on a biweekly to monthly basis until the ammonia, BOD and dissolved oxygen curves, derived from the model, fitted the measured data averaged over the period 1976 to 1980 as closely as possible (Figs. 6.1a and 6.1b). The major factor used in adjusting the demand rates was minimizing the difference between the measured and calculated oxygen curves.

6.2.4 Model predictions of effects of pollution abatement measures

The mid-summer hypolimnetic concentrations do not meet the Ministry's Provincial Water Quality Objectives (5 mg/L for warm water biota or 6 mg/L for cold-water biota for the temperature range 10-15^{o}C) unless all the CBOD, NBOD and sulphur demand loadings are removed (Table 6.1, Figure 6.3a and 6.3b). Oxygen levels are still kept below saturation

under this condition by the sediment oxygen demand. Reductions in NBOD loadings have greater effects than reduction in CBOD loadings because the rate constants for NBOD decay in the summer months are larger than for BOD decay. Reductions in the photosynthesis rate caused by reductions in phosphorus loadings have only a minor effect because of the feedback effect of decreased internal CBOD production accompanying decreased oxygen production.

Included in Table 6.1 are predictions of the effect of potential increased future loadings from the Hamilton STP if the flow is increased to design levels of 4.73 m^3/s (90 MGD) or 6.31 m^3/s (120 MGD) without change in the concentrations of ammonia and BOD. Average bottom oxygen levels as low as 0.7 mg/L are predicted.

The effects of two additional abatement scenarios - diversion of Stelco and Dofasco effluent and of Hamilton STP effluent to Lake Ontario - are also given. Although there is a significant increase, summer hypolimnetic oxygen remains continuously below Provincial Water Quality Objective levels. The scenarios assume that the existing inflow through the canal is not affected by the diversion, but that the outflow through the canal is reduced by the volume diverted.

6.3 Contributions of Various Sources and Sinks to the Dissolved Oxygen Stock

The contributions of the various sources and sinks to the harbour dissolved oxygen stock can be estimated from model calculations (Table 6.2). Reaeration is the most important source of oxygen during summer and fall. Although reaeration also predominated during spring, other sources (lake-harbour exchange, photosynthesis, tributaries and discharges) contributed almost as much as reaeration. The contribution from reaeration in spring is small because the surface waters of the harbour are then only slightly undersaturated.

Estimates of oxygen losses (including Lake Ontario), indicate that the water column oxygen demand (including carbonaceous, nitrogenous and sulphurous demands) represents about 60%, and sediment oxygen demand about 40% of losses during spring. Throughout the summer and fall, however, the water column demand predominates, as suggested by earlier studies, accounting for 80-90% of total oxygen demands in summer, and about 75% in fall. As the hypolimnetic oxygen concentration drops, the sediment demand, which varies directly with oxygen concentration, becomes smaller. At the same time, the bacterial populations in the water column are rapidly increasing.

6.4 Summary and Conclusions

1. In conducting loading reduction scenarios, it is assumed that as external waste loadings are reduced, internal loadings from bacterial decomposition of organic material are reduced equivalently by variables not allowed for explicitly in the model. Calculations, however, suggest that internal ammonia loadings may at times be equivalent to external loadings (section 4.2 and 4.3). Complete diversion of industrial and municipal effluent to Lake Ontario would eliminate all water column oxygen demands but would not necessarily eliminate sediment demand. This internal demand is dictated by primary algal production and its subsequent decomposition.

2. The model predictions are probably optimistic and the actual improvements in oxygen levels may be less than predicted, even if all of the external loadings are removed (see section 6.2.4.). Table 6.1 illustrates a number of abatement scenarios, the most optimistic of which would not meet established criteria for dissolved oxygen for at least part of the year.

3. Unless existing inputs of organic material and phosphorus are greatly reduced, sedimentation of such material and of dead algae will replenish the supply of oxygen-demanding material on the bottom, and little if any improvement in oxygen levels will result. Reductions in sediment oxygen demand would occur at an unknown rate and a trend toward improvement may not be noted immediately. However, reduction of this demand would allow a greater improvement in oxygen levels than presently predicted.

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TABLE 6.1

DISSOLVED OXYGEN LEVELS UNDER VARIOUS POLLUTION ABATEMENT SCENARIOS

Scenario	Surface Oxygen (mg/L)		Bottom Oxygen (mg/L)	
	End June	early Sept.	End June	early Sept.
1. Present conditions	7.3	7.0	1.4	1.0
2a. Universal 75% BOD removal	7.5	7.3	1.8	1.3
b. Universal 75% NOD removal	8.0	7.7	2.8	1.8
3a. Universal 25% (BOD + NOD) removal	7.6	7.3	2.0	1.4
b. Universal 50% (BOD + NOD) removal	7.9	7.6	2.6	1.8
c. Universal 75% (BOD + NOD) removal	8.2	7.9	3.3	2.2
4. Complete removal of all water column demands; sediment oxygen demand unaltered	9.2	9.0	6.4	4.9
5. Stelco and Dofasco effluent diverted to Lake Ontario	7.7	7.7	2.3	2.0
6. Hamilton STP effluent diverted to Lake Ontario	7.6	7.3	1.9	1.3
7a. Hamilton STP flow increased to 90 MGD (4.73 m^3/s) without change in concentration of NH_3 and BOD	7.1	6.8	1.1	0.8
b. As above, 120 MGD (6.31 m^3/s)	7.0	6.7	0.9	0.7

TABLE 6.2

PERCENT CONTRIBUTION OF VARIOUS SOURCES TO HAMILTON HARBOUR DISSOLVED OXYGEN BUDGET, CALCULATED FROM MODEL DATA

	Source			
Season	Reaeration	Lake -harbour exchange	Photo-synthesis	Tributaries and discharges
Spring (March - May)	32	26	18	24
Summer (June - Sept.)	55	16	16	13
Fall (Oct. - Nov.)	66	15	7	12

Numbers are percentage of total dissolved oxygen input to the harbour from the indicated source.

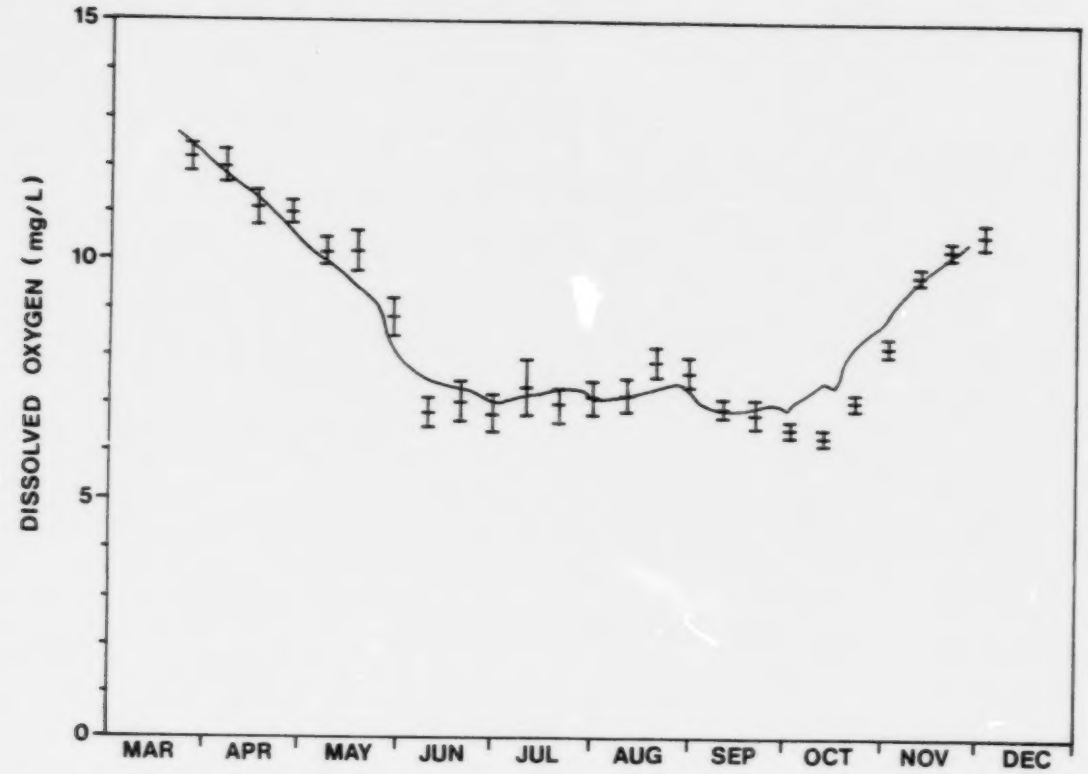

FIGURE 6.1a : PREDICTED AND OBSERVED* CONCENTRATIONS OF DISSOLVED OXYGEN FOR THE TOP LAYER OF HAMILTON HARBOUR

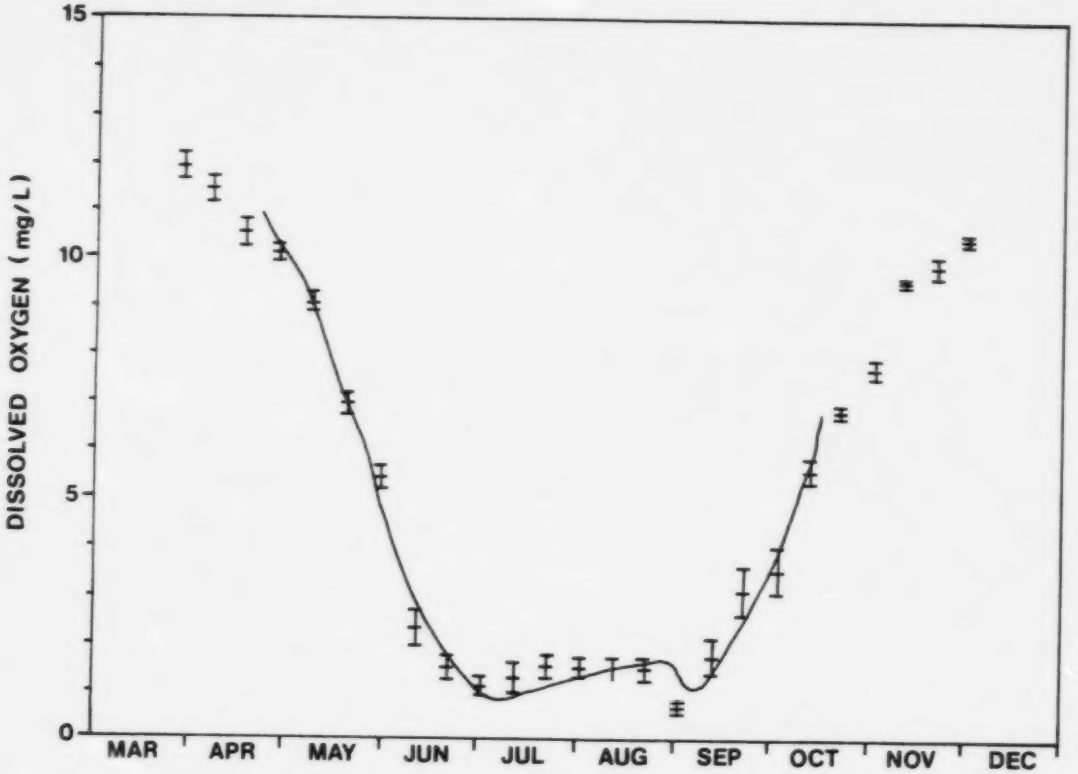

FIGURE 6.1b : PREDICTED AND OBSERVED* CONCENTRATIONS OF DISSOLVED OXYGEN FOR THE BOTTOM LAYER OF HAMILTON HARBOUR

* Observed concentrations are 10-day means over the period 1976-1980

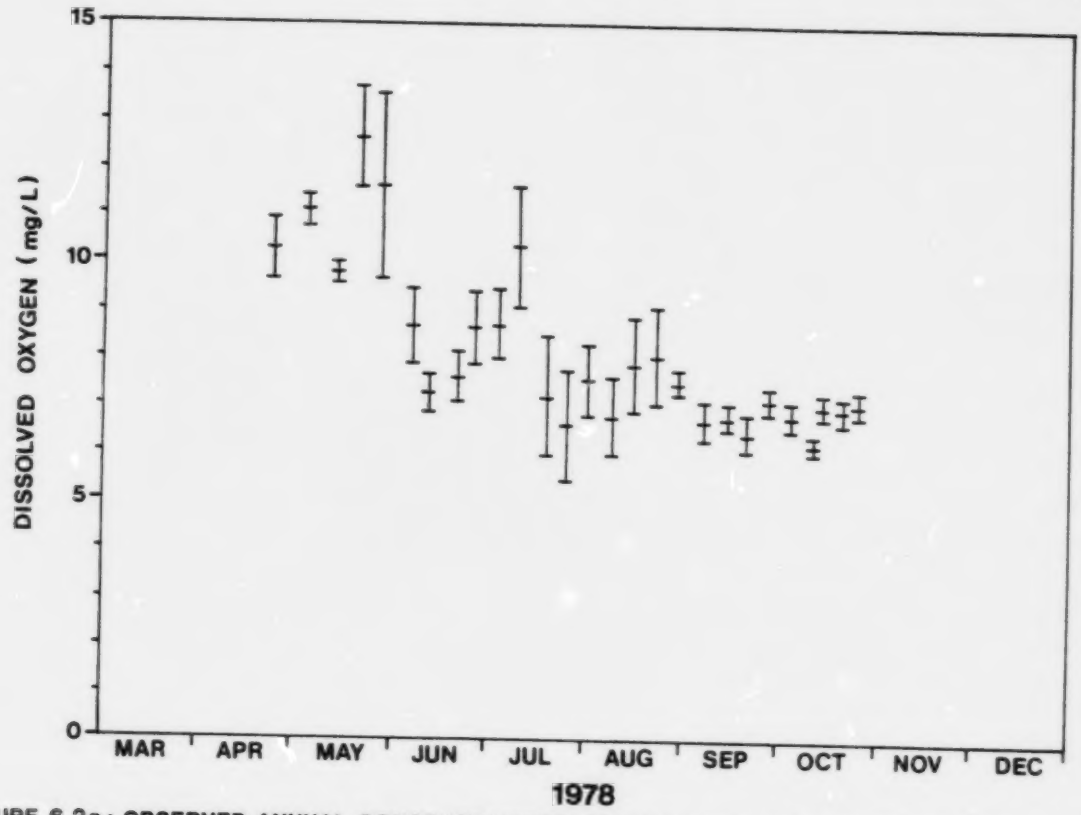

FIGURE 6.2a: OBSERVED ANNUAL CONCENTRATIONS OF DISSOLVED OXYGEN FOR THE TOP LAYER OF HAMILTON HARBOUR

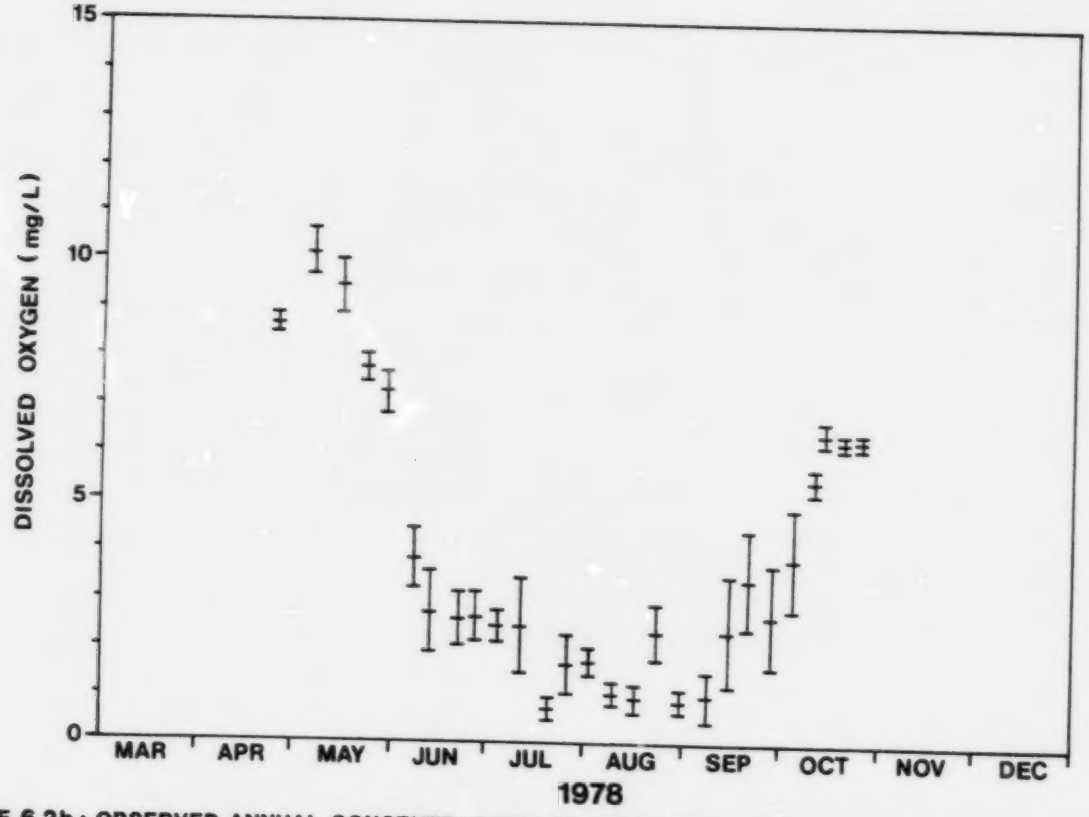

FIGURE 6.2b: OBSERVED ANNUAL CONCENTRATIONS OF DISSOLVED OXYGEN FOR THE BOTTOM LAYER OF HAMILTON HARBOUR

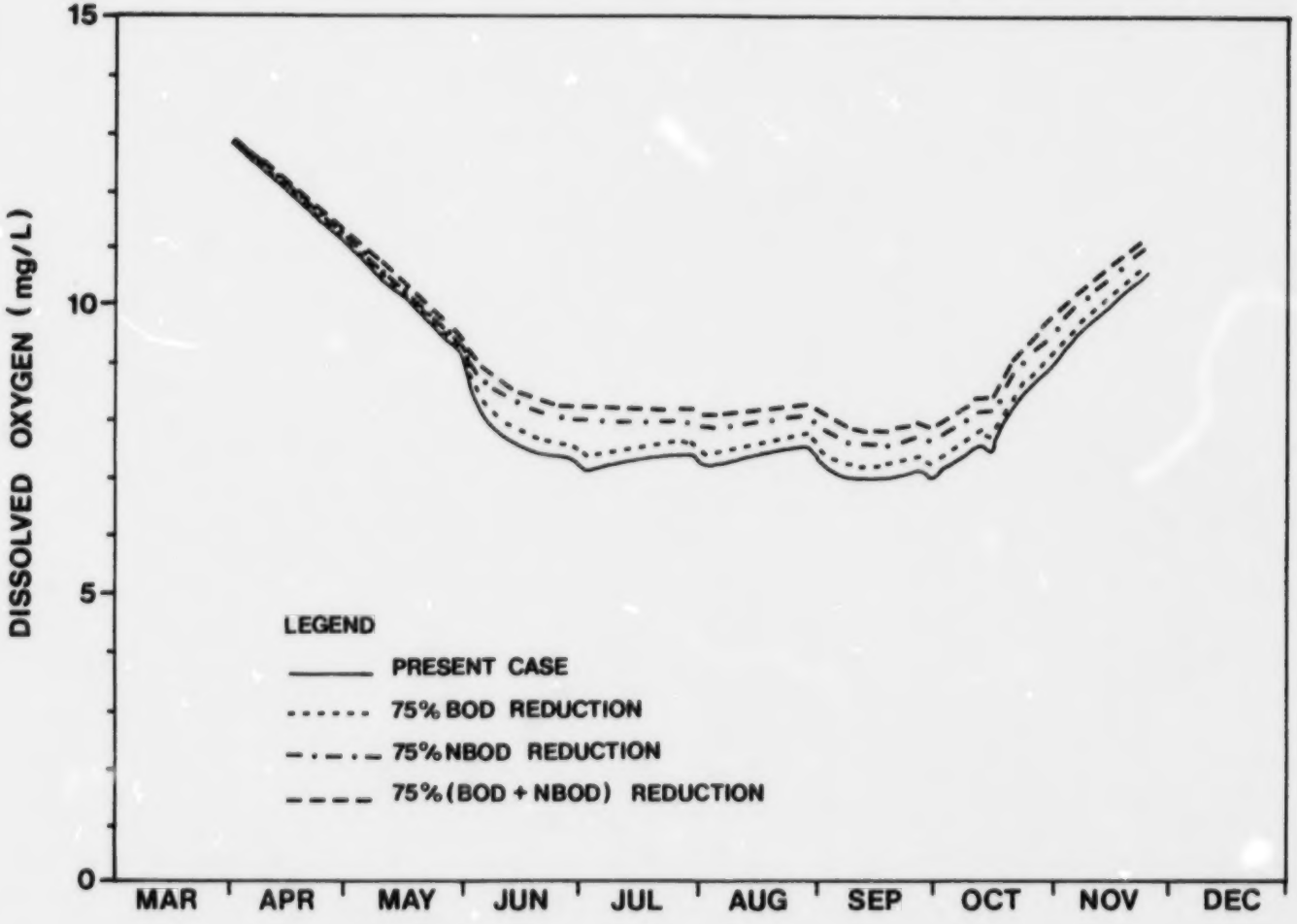

FIGURE 6.3a : EFFECT OF 75% REDUCTIONS ON DISSOLVED OXYGEN IN THE SURFACE LAYER OF HAMILTON HARBOUR

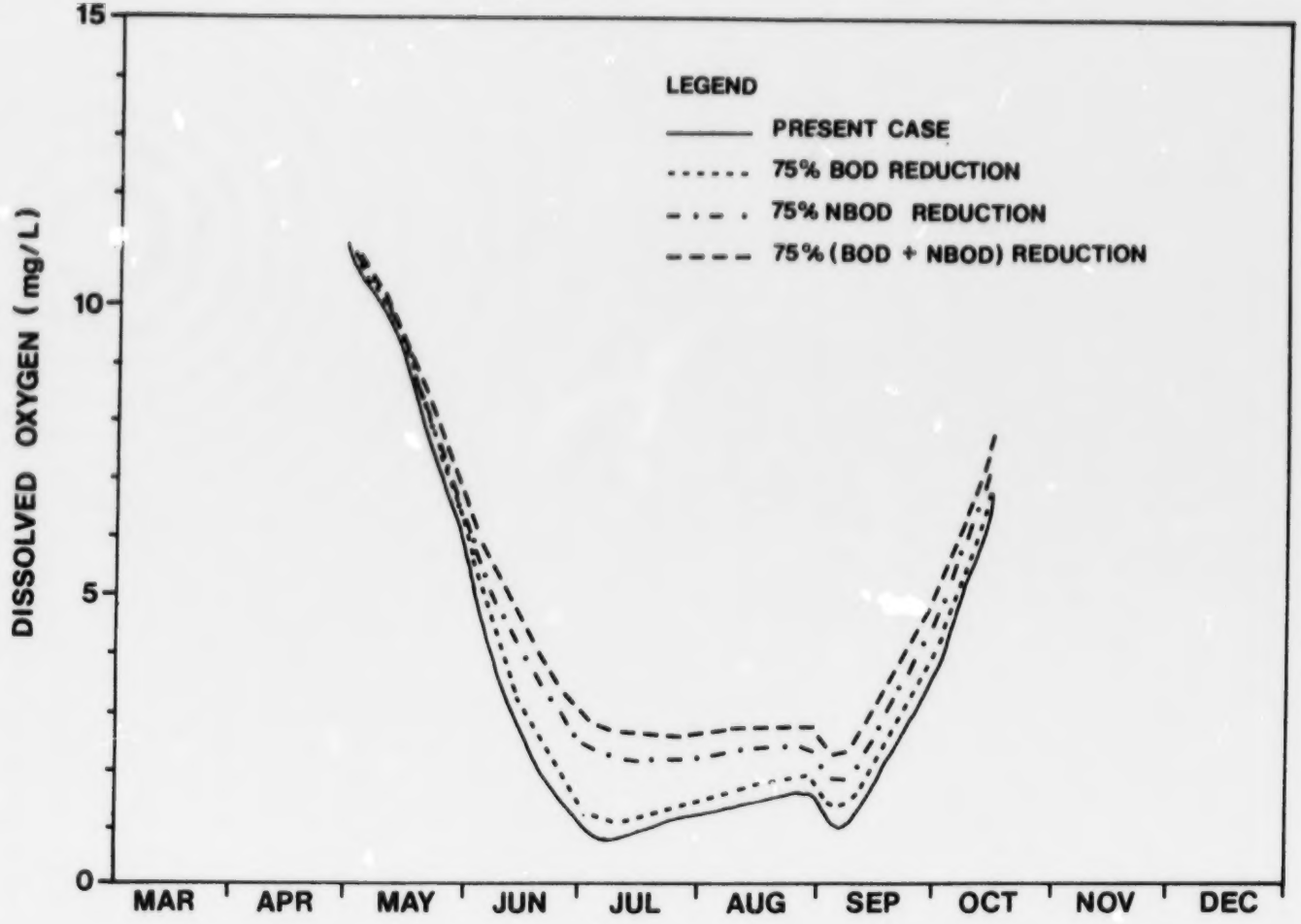

FIGURE 6.3b : EFFECT OF 75% REDUCTIONS ON DISSOLVED OXYGEN IN THE BOTTOM LAYER OF HAMILTON HARBOUR

7.0 MANAGEMENT OPTIONS

Historically, the waters of the basin and the prosperity of the community have been inextricably linked (Bailey 1983). While the tributary waters have been used to support agriculture and the lumber and milling industries, it is the harbour itself which has been responsible for the region's continued economic growth. The harbour, as a port facility, has undoubtedly been the major contributing factor to the industrialization and urbanization of the area.

Industrial growth and the improvement of port facilities have resulted in the landfilling of large areas along the southern shore of the harbour over a number of years. The marsh areas and shallow inlets were the first to be filled. The remaining portions of the littoral zone along the southeastern shore have disappeared over the years. In addition, past activities such as deforestation, drainage improvement and urban growth continue to affect water quality.

Present uses of the harbour include commercial shipping and related activities, recreational boating, industrial water supply, industrial and municipal waste disposal, and limited sport fishing. Past uses, which are presently unavailable or restricted, include commercial fishing, extensive sport fishing and swimming. The latter use is and has been prohibited for a number of years through a by-law.

In the past, both the industries and the municipalities have responded positively to MOE effluent requirements designed to protect and improve harbour water quality. Dramatic improvements to the quality of all point source effluents entering the habour have been achieved since the mid-1960's. The abatement program has taken a case-by-case, parameter-by-parameter approach, with the aim of restricting the contaminants entering the environment and improving the trophic character of the receiving water body. As a result, the majority of the material responsible for enrichment and oxygen depletion has been reduced from municipal and industrial sources at a cost which exceeds 250 million dollars. At present, the effluent concentrations for conventional parameters (BOD, SS and TP) from both municipal and

industrial sources meet province-wide objectives. Decreasing concentrations of some organic and inorganic contaminants which are presently of concern or in exceedence of guidelines would require the application of advanced technology.

Despite these major improvements, the harbour is still a prime area of concern in the Great Lakes (IJC 1984). One of the largest factors contributing to the harbour's present state is the level of contamination of the sediments. Present inputs from the point sources continue to provide an environmental stress which cannot be assimilated by the harbour ecosystem. Furthermore, reductions to the present loads will be even more expensive, on a kilogram-for-kilogram basis, than they were in the past.

For these reasons, if MOE guidelines and objectives (MOE 1984) are to be met in the harbour, new abatement initiatives, with accompanying large capital expenditures, will be required on the part of industry, the area municipalities and other responsible agencies.

Three broad, but distinct options for managing water quality in Hamilton Harbour are available: No Exceptional Abatement; Maintain Status Quo; and Enhancement. These represent increasing levels of environmental protection; higher levels of protection therefore carry increased capital and implementation costs. Control of contaminants, at their source, will proceed on a case-by-case, parameter-by-parameter approach regardless of which water quality management option is selected.

Factors which may guide the selection of a particular management approach include an evaluation of the present and potential resources of the harbour and an inventory of present and desired uses. The option chosen would attempt to reconcile these with present water quality.

The following paragraphs provide a brief summary of each of the three suggested options.

1. No Exceptional Abatement

At present, the discharges of conventional contaminants which affect aesthetics, enrichment and oxygen demand are at or near Provincial Objectives. These requirements are based on the concentration of a particular contaminant in final effluents.

This option, if adopted, would follow the existing guidelines and therefore, no further reductions in municipal or industrial point-source effluent concentrations would be required. Municipal non-point source discharges would be required to conform to the new Provincial policy (presently in draft form) governing combined sewer separation; however, the Hamilton area would not be viewed as a special case.

This approach would maintain the present, documented uses and minimize the cost of pollution abatement. It would not however correct the existing environmental problems associated with enrichment and oxygen depletion, nor prevent further environmental deterioration from urban or industrial inputs as the basin loadings increase. This option is not in accord with present MOE Water Management policies which do not allow for degradation beyond present conditions.

2. Maintain Status Quo

This approach differs from option 1 in that point-sources would be controlled at existing loading levels. This would maintain harbour water quality in its present condition by limiting the total inputs of certain parameters to specified amounts.

While this option would prevent further degradation in harbour water quality it does not provide any improvement for existing problems. Growth and development in the basin could be restricted by limits on specified contaminant loads. Were the industries and municipalities to expand, abatement costs would increase to maintain the present loads.

3. Enhancement

The "Enhancement" option would provide for improvement in harbour water quality. There are many environmental improvement measures that could be employed individually or in combination to achieve this end. These measures would produce a spectrum of environmental improvements ranging from minimal to complete amelioration of present conditions. These improvement measures are not achievable without substantial costs; therefore, the financial burden, any adverse ecological effects and the environmental benefits of each possible measure must be fully assessed before an "Enhancement" strategy is selected.

A number of possible improvement measures are described in the following table. For discussion purposes, these have been broadly categorized on the basis of their estimated unit cost as follows: low cost - less than one million dollars in total; medium cost - between one and five million dollars; and high cost - more than five million dollars. In general, the lower cost measures address aesthetics and to some degree the physical habitat for fish, while the higher cost measures address major improvements to water quality.

Possible Management Measures for Hamilton Harbour

Low Cost Measures

1. macrophyte planting
2. construction of artificial reefs
3. fish stocking
4. landscaping of harbour shoreline

Medium Cost Measures

1. dredging of Windermere Basin
2. diversion of municipal sewage treatment plant effluents to Lake Ontario.
3. obtain industrial water supply from Lake Ontario.
4. hypolimnetic aeration.

High Cost Measures

1. erosion control in surrounding basin
2. stormwater retention facilities in basin
3. in-place pollutant treatment (dredging, capping, chemical inactivation of harbour sediments)
4. application of best available treatment standards to industrial and municipal discharges.
5. combined sewer separation
6. diversion of industrial discharges to Lake Ontario.
7. Waterfront commercial/recreational development.

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